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THE ACCUMULATION OF ENERGY BY PLANTS

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A century ago the chief concern of civilization was the search for new sources of materials and for more effective ways of using them. During the past quarter century the realization has been growing that our energy resources are even more important and definitely limited. Our present social and economic status has been built largely through the use of the energy of coal, petroleum and gas. The ever threatening spectre of their exhaustion has turned the attention of many toward sunlight and plants—the original source of this geologically inherited capital. Plants will always be the primary food supply. Certain optimistic engineers have also proposed to solve the future fuel problem using plants as the gatherers of the sun's energy.

It has therefore seemed profitable to study this problem of the accumulation of energy by plants both for what information it may give as to our future energy resources, and for its interest as a picture of plant metabolism from the energy point of view. Why the energetics of *plant* metabolism have seemingly lagged so far behind those of *animal* metabolism will be more apparent if we digress for a moment and look into the history of our knowledge of animal and plant metabolism.

The study of the metabolism of animals has been in progress for two and a half centuries. It had its beginning apparently in the experiments of Hooke (1667) and Mayow (1674). The latter seems to have clearly recognized the necessity of something in the air, which we now call oxygen, both for the maintenance of combustion and of vital activity in animals. Mayow's work seems to have been overlooked in the development of the

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"phlogiston theory" during the succeeding century, and in 1774 Priestley rediscovered oxygen and its importance in the metabolism of animals

With the writings of Lavoisier (1774-1789) came more precise proof that the gas exchanges involved in combustion and in respiration are essentially the same. Lavoisier built and used the first ice calorimeter and thereby attempted to show that the heat energy liberated in the animal body is derived from the oxidations taking place in metabolism

Seventy years later, Regnault and Reiset (1849) advanced our knowledge of these processes with definite recognition of the so-called "respiration ratio," that is, the ratio of the volume of carbon dioxide released to volume of oxygen consumed. They showed quite definitely that the value of this ratio depends upon the food consumed. It is about unity when carbohydrates are consumed and less than unity when proteins and fats are used as food

It was not until 1892, however, that a sufficiently accurate calorimeter was constructed by Rubner to show that in metabolism the energy income and outgo also constitutes a balance. Rubner introduced the "closed system" calorimeter in which experiments could be performed with animals for several days at a time. With his equipment it was possible to determine the potential energy of the food, the amount of oxygen consumed, the amount of carbon dioxide liberated, the energy released and the potential energy still present in the body wastes. In this way he was able to secure results which established that fundamental law of metabolism, that energy is neither created nor destroyed within the animal body, that the energy liberated is equal to the potential energy of the food consumed, and that the conservation of energy is just as true within the animal body as it is in the environment

However Rubner's determinations had an error of about one per cent, and this is too large for the complete establishment of a law. The more recent experiments of Atwater and Benedict conducted both with animals and men have finally removed the last doubt about the possibility of any other sources of energy. As a result of their work we know not only the precise metabolic energy values of a great variety of foods but we have exact determinations of the energy output under a great variety of environmental conditions, with the body at rest and in action, in health and in disease. Indeed these studies have

been so enlightening that the metabolic rate has become an important method of diagnosis in medicine

Finally, these studies of animal metabolism have established the fact that foods in addition to furnishing the material for the development and growth of the body, provide the energy to maintain bodily temperatures, for internal and external work, and for the synthesis of other substances found in the body

The study of the metabolism of plants is a very different matter Priestley (1774) showed that the "spoilt air" given off by animals would again support combustion and animal life if exposed to green plants in the light

Ingenhous (1779) and De Saussure (1804) proved that plants absorb carbon dioxide and give off oxygen in sunlight and that these gas exchanges are reversed at night De Saussure proved that the increase in dry weight of green plants occurs only when exposed to carbon dioxide It remained for Dutrochet (1837) to show the connection between this process, which we now call photosynthesis, and the green tissues of plants and also that respiration in plants and animals is fundamentally the same

A little later Leibig (1840) corrected the then prevalent notion that plants obtain all or a part of their carbon from the humus of the soil But he seems to have had wholly erroneous notions of photosynthesis and respiration, and went so far as to deny that respiration comparable to that of animals occurs in plants In spite of the excellent start toward a correct interpretation of photosynthesis and respiration, as late as 1860 the prevailing view seems to have been that plants merely exhibit two kinds of respiration, the one a diurnal and the other a nocturnal process

All these early students of plants were denied an intelligent insight into the metabolism of plants because of their assumption from animal physiology that the food of a plant must come from the outside, a fallacy that is still being perpetuated by those who persist in speaking of "the plant food in the soil"

To Sachs (1865) belongs the honor of having first clearly stated the fundamentals of plant nutrition, and the connection between the chloroplasts and photosynthesis Becquerel (1868) made the first attempt to determine the per cent of sunlight used by plants in photosynthesis on the basis of the plant materials produced per hectare and concluded that only about 4 of one per cent is utilized The work of Sachs, Becquerel, and

Boussingault ushered in the modern period of our knowledge of plant metabolism

The fact that in green plants exposed to the light photosynthesis, an energy consuming, or endothermic reaction, proceeds along with respiration, an exothermic process, complicates the study of metabolism of plants far beyond that of animals. There is seemingly no way by which the complementary gas exchanges involved in these two processes or the energy transformations can be simultaneously investigated. We can make short-time determinations of either process, and we can alternate light and darkness, and by modern methods of analysis obtain much information concerning both processes. At the same time it is clear that under these experimental conditions the relative amounts of carbohydrates and amino acids also change and with them the rate of respiration. At best we can make observations of but a few hours duration, and piece together the fragmentary determinations of energy income and outgo, and the relative rates of oxygen and carbon dioxide exchange. To complete the picture we should also be able to measure simultaneously the energy of sunlight.

It is just twenty years since Horace Brown (1905) presented to the Royal Society of London an energy budget of a green leaf¹. This was the first attempt on an experimental basis to describe the metabolic processes of a plant organ in terms of energy income and outgo. Among other things he determined the proportion of light energy utilized by the leaf in photosynthesis, how much is absorbed, and how much passes to the environment. About the same time F. F. Blackman also published several papers that contributed to our information concerning the rates both of photosynthesis and respiration. The most notable recent contributions are those of Spöhr who has corrected certain wrong impressions of the steps in these processes, and is gradually building a secure foundation for an understanding of the details of plant metabolism. But there is no probability that we shall have in the near future an experimental determination of the energy budget of a complete plant such as we have for a great variety of animals.

¹Brown, H. T. The Reception and Utilization of Energy by a Green Leaf. *Nature* 71:522-526, 1905. See also for details: *Proceedings Roy. Soc. London*, Series B Vol. 76, which contains several papers by Brown and one by F. F. Blackman.

The work of the animal physiologists and the studies of non-green plants have shown that an energy budget can be calculated from the heat equivalents of food substances consumed and that the results so obtained are quite close to the results obtained by calorimetric experiments. Since there is no elimination of solid materials from plants, we have an advantage in that our calculations are not complicated by the energy content of these waste products.

As a result of measurements begun by Langley and continued by Abbott and his associates of the Smithsonian Institution we now have accurate determinations of the solar energy received at the earth's surface for a number of stations in the United States and these may be taken as the basis of our energy income.²

The chemical and physiological studies of crop plants at our Agricultural Experiment Stations have made available many data concerning dry weights, chemical composition, water requirements, and rates of respiration and growth. It ought therefore to be possible utilizing these figures to estimate the energy income accumulation and outgo with sufficient accuracy to approximate a real energy budget for some of these plants.

Corn has been selected for this particular study because it probably represents the most efficient annual of temperature regions. It grows steadily throughout the season and forms a closed association sooner than any other of our crop plants. Moreover there are available more data concerning corn than other crop plants.³ Let us now examine the energy budget of a hypothetical acre of corn in the heart of the corn belt in north central Illinois where corn attains yields as great as anywhere, and not far from Madison, Wisconsin, one of the stations at which solar radiation has been studied. The growing season is from June 1 to September 8 one hundred days. The best yields have been with 10,000 plants to the acre. One hundred bushels, with a dry weight of 2160 kg per acre, is the yield assumed

²Kimball, H. H. Variations in the Total and Luminous Solar Radiation with Geographical Position in the United States. Monthly Weather Review 47 709-793 November 1919.

³Vivian, Alfred. First Principles of Soil Fertility pp 9-11 1908.
Latshaw and Miller. Elemental Composition of the Corn Plant. Jour Agr Research, 27 845-859 1924.

Briggs and Shantz. The Water Requirements of Plants. Bur Plant Indus Bull 284 and 285 1913.

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Kisselbach, T. A. Transpiration as a factor in Crop Production. Nebraska Agric Exper Sta Tech Bul 6 1-214 1915.

although it is not a maximum crop for the corn belt. How well an acre of corn covers the area is shown by the fact that during the latter half of the season nearly two acres of leaves are exposed to the light

TABLE 1 AVERAGE ELEMENTAL COMPOSITION OF THE CORN PLANT

Corn Plant	{	Water 79 7%	{	Organic matter 19 5%	{	Carbohydrates	12 2
						Fiber	5 0
Corn Plant	{	Dry matter 20 3%	{	Mineral Elements 0 8%	{	Fat	0 5
						Protein	1 8
						C —	44 58
						O —	43 70
						H —	0 26
						N —	1 43
						K —	1 62
						P —	25
						Ca —	59
						Mg —	44
						Fe —	10
						S —	05
						Cl —	20
						Na —	15
						Si —	54

At maturity the average corn plant contains about 20 per cent of dry matter and about 80 per cent of water (Table 1). Of the dry matter, carbon makes up about 44 58 per cent. This is the most important figure for our calculations derived from the chemical analyses of the corn plants. We must also know the total amounts of mineral elements present which is 5 37 per cent from which we can derive the fact that 94 63 per cent of the plant's dry weight is organic matter. The dry weight of an average corn plant growing under these circumstances is 600 g, of which 216 g makes up the grain, 200 g the stalk, 140 g the leaves, and 44 g the roots. The total weight of the 10,000 plants is 6000 kg. Subtracting from this the 322 kg of mineral elements in the ash we have left 5678 kg of organic matter, of which 2675 kg is carbon.

TABLE 2 GLUCOSE EQUIVALENT OF ACCUMULATED CARBON

Dry weight of ave. plant 600g	{	grain	216
	{	stalk	200
	{	leaves	140
	{	roots	44
Total dry wt. of 10,000 plants			= 6000 kg
Total ash (5 37% of dry weight)			= 322 kg
Total organic matter of acre			= 5678 kg
Total carbon accumulated (44 58%)			= 2675 kg
Glucose equivalent of accumulated carbon			= 6687 kg
$C_6H_{12}O_6 \quad C_6 = 180 \quad 72$			

To estimate the amount of photosynthesis we must determine the amount of carbon, because carbon enters the plant only by photosynthetic reduction of CO_2 . The total carbon is 2675 Kilograms and the glucose equivalent of this carbon is 6687 kilograms. This is the amount of primary sugar equivalent to the carbon accumulated in the mature plant (Table 2)

TABLE 3 GLUCOSE EQUIVALENT OF RESPIRATION

Estimated rate of CO_2 release = 1% of the dry wt per day	
Average dry weight for season ($\frac{1}{2}$ total wt)	= 3000 kg
Average rate of CO_2 release (01 \times 3200) per day	= 30 kg
Total CO_2 release during season	= 3000 kg
Carbon equivalent C CO_2 = 12 44	= 818 kg
Glucose equivalent $\text{C}_6\text{H}_{12}\text{O}_6$ C_4 = 180 72	= 2045 kg

At maturity however, only a part of the carbon remains for some has been lost as CO_2 in respiration (Table 3). The average rate of CO_2 loss is not far from one per cent of the dry weight per day. This would cause a daily loss of 30 kilograms of CO_2 , and during the entire season a loss of 3000 kilograms. The glucose equivalent to this amount of carbon dioxide is 2045 kilograms.

Adding the amount of this lost glucose to the glucose equivalent of the carbon in the plant, gives the total glucose manufactured as 8732 kilograms. It requires energy equivalent to 3760 calories to produce one kilogram of glucose. Hence it required not far from 33 million calories to produce the entire photosynthetic product (Table 4)

TABLE 4 ENERGY CONSUMED IN PHOTOSYNTHESIS

Glucose equivalent of accumulated carbon	6687 kg.
Glucose equivalent of carbon oxidized	2045 kg
Total glucose manufactured	8732 kg
Energy required to produce 1 kg glucose	3760 Cal
Total energy consumed in photosynthesis	33 million Cal

We are now in a position to estimate the efficiency of the corn plant as a photosynthetic agent (Table 5)

TABLE 5 EFFICIENCY OF PHOTOSYNTHESIS

Total energy available on acre during the growing season	2043 million Cal
Total energy used in photosynthesis	33 million Cal
Per cent of available energy used by the corn plant in photosynthesis (efficiency of corn plant)	1.6%
Of the total light spectrum measured, however only about 20% is used in photosynthesis, hence the efficiency of the photosynthetic process is	9%

The total energy available according to the Smithsonian figures is 2043 million Calories. The energy utilized is 33 million,

or 16 per cent. In photosynthesis however, only certain rays are effective and these furnish about 20 per cent of the energy measured by the pyrheliometer ⁴. Consequently the efficiency of photosynthesis in 100-bushel corn is 8 per cent.

Another source of energy loss to the plant is transpiration. From the water requirement studies of corn it is probable that in Illinois not far from 276 kilograms of water are evaporated during the growing season for every kilogram of its dry weight (Table 6). The total weight of water lost in this way therefore is one and a half million kilograms. This is equal to 408,000 gallons or sufficient water to cover the acre to a depth of fifteen inches.

TABLE 6 ENERGY CONSUMED IN TRANSPIRATION

Total dry weight of the aerial parts	3500 kg
Estimated rate of water transpired per kg. of dry matter per season	276 kg
Total water transpired by the acre	1.5 million kg
Energy required to evaporate 1 kg. water at the average temperature of growing season	593 Cal
Total energy consumed in transpiration ($593 \times 1,534,560$)	= 910 million Cal
Of the available energy (2043 million Cal.) transpiration consumed about	44.5%

The energy necessary to evaporate one kilogram of water at the average temperature of the growing season is 593 calories. Consequently 910 million Calories are expended in this way. This is equivalent to 44.5 per cent of the available energy.

TABLE 7 ENERGY RELEASED IN RESPIRATION

Glucose consumed in respiration	2045 kg
One kilogram of glucose releases	3760 Cal
Total energy released in Respiration	7.7 million Cal
Of the energy made potential in photosynthesis Respiration releases	23.4%
Assuming that photosynthesis goes on 12 hours each day and respiration 24 hours each day the average daily rate of photosynthesis is about 8 times the rate of respiration	

Respiration again releases a part of the energy rendered potential in photosynthesis. As we have seen 2045 kilograms of glucose are thus oxidized, and in consequence 7.7 million

⁴For the region of north central Illinois Professor Abbot estimates that the proportion of total energy contained among the rays utilized in photosynthesis is as follows:

Wave length limits	Air Mass 2	Air Mass 3
070-035 μ	4.6%	4.5%
022-597 μ	3.4	3.1
547-565 μ	3.0	2.7
544-530 μ	1.9	1.7
495-420 μ	9.0	7.3
Total	21.9%	19.3%

Calories are released within the plant. This energy raises the temperature of the plant and escapes to the environment, or it is used in synthesis of fats, proteins and other reduced organic substances.

The energy released in respiration amounts to 23.4 per cent – almost one-fourth of the energy absorbed in photosynthesis. This is far more than is needed to account for the endothermic reactions associated with food transformations within the plant.

Assuming that photosynthesis goes on 12 hours and respiration 24 hours each day, the average rate of photosynthesis must be about 8 times the rate of respiration.

TABLE 8 SUMMARY OF BUDGET

Total energy available	2043 million Cal
Used in photosynthesis	33 million Cal
Used in transpiration	910 million Cal
Total energy consumed	943 million Cal
Energy not directly used by the plants	1100 million Cal
Energy released by respiration	8 million Cal
Of the available energy 100-bushel corn uses about	46%
The environment takes up about	54%

We may now summarize the energy budget. The total income is 2043 million Calories. The expenditure for photosynthesis and transpiration is 943 million Calories. Respiration returns 8 million Calories. Therefore the plant uses about 46 per cent, and the environment takes up 54 per cent. As a result we are in a position to make a number of generalizations regarding the metabolism and growth of plants, both as to materials and energy.

1 An acre of 100-bushel corn uses during the growing season about 408,000 gallons of water or 15 acre-inches.

2 The evaporation of this water consumes about 45 per cent of the available light energy.

3 In photosynthesis the corn plant utilizes about 1.6 per cent of the energy available, its efficiency is about 8 per cent.

4 An acre of 100-bushel corn manufactures on the average 200 pounds of sugar a day.

5 Of the energy rendered potential in photosynthesis, 23.4 per cent is again released in respiration.

6 Of the sugar manufactured nearly one-fourth is oxidized in respiration.

7 Respiration releases several times as much energy as is needed to account for the reductions in the synthesis of fats, proteins and other compounds.

8 At maturity the grain contains about one-fourth of the total energy utilized in photosynthesis, or about 5 per cent of the energy available

9 The average rate of photosynthesis is about eight times the rate of respiration

10 Since the young corn seedling weighs 3 grams and the mature plant weighs 600 grams, on the basis of the compound interest law of growth the average daily increment in dry weight is 7.9 per cent

Returning now to the questions proposed in the introduction to this paper regarding future food and fuel supplies. If corn is the most efficient of our temperate zone crop plants, and if 100-bushel corn can utilize only 1.6 per cent of the available energy, it must be apparent that the average crop plant falls far below this amount. It is evident also that we can never expect many of our other crop plants in temperate regions to equal this production, and we must agree that plants are very inefficient gatherers of energy.

The suggestion that our liquid fuels, petroleum and gasoline, may some day be replaced by alcohol made from plants is quite unreasonable. A little figuring will show that to substitute the energy of alcohol for the energy now being developed from gasoline would require all the corn now being grown in the United States.

The solution of our future fuel energy supplies lies rather in the discovery of the physics and chemistry of photosynthesis. We have in the past discovered the nature of many biological processes.

It is not so many years ago since it was thought that only plants and animals could synthesize organic compounds. Now we can make hundreds of them more efficiently than either plants or animals. There is no good reason to think that photosynthesis is impossible of explanation and imitation. Photosynthesis is a very inefficient process, but when we once know its photo-chemical basis we should be able to improve on it greatly and herein lies the best hope of future supplies of energy, almost unlimited and certainly inexhaustible.

THE ALIMENTARY CANAL OF PASSALUS*

HAROLD C LEWIS

INTRODUCTION

It has long been known that the alimentary canal of *Passalus cornutus* Fab harbors an extensive associated flora and fauna. Also, its sub-social habits have attracted some attention. Because of this and its specialized food habits *Passalus* offers an interesting problem in tracing the results of such specialization upon the digestive canal. This paper is not intended as a final and complete work, but more as a preliminary discussion dealing especially with the morphology of the alimentary tract.

The writer wishes to express his appreciation to Mr A A Mathewson, who did half of the work in the preparation of the slides and then accepted a position precluding further study, and to Dr C H Kennedy, under whose direct supervision this work has been carried on.

Leidy (1851) first called attention to the flora and fauna in the hind intestine of *Passalus cornutus*. He gives a short description of the alimentary tract using a slightly different terminology from that generally used at present. Considering the attachment of the Malpighian tubules as a landmark in setting off the hind-intestine from the mid-intestine, the pro-ventriculus as used by Leidy consists of the fore-intestine and the mid-intestine, which includes the ventriculus or true-stomach. The ventriculus as used by Leidy is a part of the hind-intestine, since it is set off from the mid-intestine by the attachment of the Malpighian tubules and is lined with a chitinous intima. This part of the hind intestine is here considered as the ileum and harbors the extensive flora and fauna as described by Leidy. The flora of fungi is limited to the distal portion of the ileum, which is characterized by numerous sacculi or folds of the intestinal wall.

In all the beetles examined, these fungus gardens were present and it seems that their occurrence is regular in the specialized ileum of *Passalus cornutus*. Mr R H Painter, of this department, has successfully cultured two of these fungi.

* Contribution from the Department of Zoology and Entomology, Ohio State University, Number 83

Leidy describes several fungi, *Enterobryus attenuatus*, *Arthromitus cristatus*, *Cladophytum comatum*, and *Corynocladus radiatus*, as being fixed parasitic on the mucous membrane of the intestine. He also describes an elongated tubular cellule and a granulo-filamentous phytoid substance as parasitic phytoid bodies, the exact nature of which he was uncertain, and several pseudo-entophyta. *Gregarina Passalicornuti* and *Hystriognathus rigidus* are listed as being associated with the flora of the intestinal canal.

The relation of many insects to micro-organisms has occupied the attention of a few investigators. It has been shown in some cases, Baumberger (1919), that micro-organisms furnish food for the insects. In others the organisms exist as parasites, while in some a symbiotic relationship occurs, as Cleveland (1924) has proved to be the case with termites. Leidy considers these organisms as being parasitic within the alimentary tract of *Passalus*. However, their regular occurrence and the specialized food habits of the beetle suggests the possibility that this may not necessarily be so. Some of these intestinal fungi may play an important part in the physiology of digestion. Further work on the digestion and the embryology of the alimentary tract seems to be necessary to clear up this relationship. Leidy pointed out that the millipede, *Julus marginatus*, which also lives on decaying and rotting wood, has an extensive floral and faunal association.

THE GROSS ANATOMY OF THE ADULT CANAL

The alimentary canal of the adult beetle shows considerable specialization in form and structure. In accordance with the general rule that in herbivorous insects the alimentary tract is longer than in carnivorous insects, in *Passalus* it is a winding convoluted tube about three times as long as the body. The canal makes three complete loops and turns back on itself twice. Three chief divisions of the tract are readily recognized, which are the fore-intestine (stomodeum), the mid-intestine (mesenteron or ventriculus), and the hind intestine (proctodeum). The general form of the gross anatomy is shown in Fig. 1.

The fore-intestine is a straight, comparatively short tube extending from the mouth to about the beginning of the mesothorax. The pharynx is evident as a slight dilation of the tract in the head. The oesophagus is a slender elongate tube, extend-

ing into the prothorax, where it gradually enlarges to form the crop. The mid-intestine is separated from the fore-intestine by a constriction composed of two distinct rings.

The mid-intestine is a long coiled tube making three complete loops. It is almost uniform throughout and excepting the posterior tip is covered by numerous small papillae, which are crypts or diverticula of the digestive epithelium. These give it a white maculated appearance.

The hind-intestine, which is somewhat shorter in length than the mid-intestine, is divided into four regions. Poyarkoff (1910) recognized four parts in the hind intestine of a Chrysomelid, *Gallerucella luteola*, according to Wood (1916). There are four distinct divisions of the hind intestine of *Passalus* which are considered as the proximal portion of the ileum, the distal portion of the ileum, the colon, and the rectum. The first region, the proximal portion of the ileum, is comparatively short and appears much the same as the mid-intestine, except that it is not covered by papillae. The distal portion of the ileum is much larger and longer and is characterized by numerous large folds of the intestinal wall. It is in these folds that the intestinal fungi live. This part of the ileum extends almost directly caudad for over half of its length and then turns cephalad. The colon is a long, slender tube forming a large semicircle on top of the coiled ventriculus, straightening out towards the tip of the abdomen. The rectum is short, but is evident as a slight enlargement of the tract somewhat lighter in color than the colon.

For a discussion of the mouthparts and skeletal elements, see Landacre (1902).

The succeeding discussion of the histological structure of the alimentary canal is taken up in order, beginning at the anterior end.

THE HISTOLOGICAL STRUCTURE OF THE FORE-INTESTINE

Pharynx—In *Passalus* this region is evident as a slight enlargement of the tract with a heavy chitinous lining continuous with that of the body wall. The primary intima is covered with fine chitinous spines which project caudad. The secondary intima appears slightly fibrillar, almost transparent, and is much thicker than the primary intima. The epithelium consists of a definite layer of small irregular cells. The muscle layers are much the same as in the oesophagus.

Oesophagus —The intima of the oesophagus is thrown into a series of longitudinal folds (Fig 2) These are irregular and usually are six in number The primary intima is well developed and is covered by numerous spines of varying lengths The secondary intima is much thicker and is almost transparent (Fig 3)

The epithelium of the oesophagus consists of irregular cuboidal cells The basement membrane is present

The longitudinal muscles form a layer covering the epithelium They do not all run directly longitudinally, but intertwine considerably, so that cross-sections of this region show many of them running in an oblique fashion All sections made show that the space between the epithelium and circular muscular layer is not completely filled by these longitudinal muscles

The circular muscles form a layer covering the longitudinal muscles This layer varies somewhat in thickness and forms a complete covering around the tract

Crop —In the crop the lumen is wider than in the oesophagus, the epithelium is thinner, and the chitinous folds are much smaller

The primary intima is thin and lacks the chitinous teeth of the oesophagus The secondary intima is much thicker and is almost transparent

The epithelial cells of the crop are much like those of the oesophagus, except that in places instead of being cuboidal they are flattened In some of them appear irregular sphere-like bodies, somewhat larger than the nuclei and which stain black with Delafield's haemotoxylin and eosin The identity and nature of these Rickettsia-like bodies is undetermined They are found only in the crop and in that portion of the fore-intestine forming the fold of the oesophageal valve The basement membrane is well defined

The longitudinal muscles are much less in evidence than in the oesophagus Anteriorly they continue into the oesophagus and posteriorly end in the fold of the oesophageal valve (Fig 11)

The circular muscles are more in evidence than the longitudinal muscles They form a complete layer around the canal much the same as in the oesophagus

Oesophageal Valve —In the transition from the fore-intestine to the mid-intestine, the fold of tissue composing the oesophageal

valve is well developed (Fig 11) The structure of the wall of the fold is much like that of the wall of the crop Intima, epithelium, basement membrane, longitudinal and circular muscle layers are present The intima ends gradually, in longitudinal section, coming to a point on the posterior face of the valve

The intima disappears on the posterior face of the fold which marks the limits of the fore-intestine

The epithelial cells of the anterior face of the oesophageal valve continue much the same as in the crop until just before reaching the tip of the fold Here the cells begin to elongate and become gradually longer on the posterior face of the valve until the end of the fore-intestine is reached At this point a ring of spindle-shaped cells is encountered which terminates the epithelium of the fore-intestine The turgid appearing digestive epithelial cells follow immediately after this ring of spindle-shaped cells

The exact nature of this ring of spindle-shaped cells is undetermined It marks the limits of the fore-intestine and possibly may be the imaginal disc of some authors The nuclei of these spindle-shaped cells contain almost no deep-staining chromatin material, whereas, the nuclei of both the epithelial digestive cells of the stomach and the epithelial cells of the fore-intestine contain much deep staining material The basement membrane is continuous from the fore-intestine to the mid-intestine

The longitudinal muscles of the fore-intestine end near the tip of the anterior face of the oesophageal valve In the tip of the fold there are no muscles whatever On the posterior face of the fold the longitudinal muscles of the mid-intestine begin They are fewer in number and smaller than those of the fore-intestine

The circular muscles of the fore intestine end at about the middle of the anterior face of the oesophageal valve At this point they are much smaller in size than the longitudinal muscles The circular muscles of the mid-intestine appear soon after the longitudinal muscles of the mid-intestine begin They are small isolated strands

The peritoneal membrane is not concerned in the fold of the valve, but is continuous from the fore-intestine to the mid-intestine Along with it run several fibers of longitudinal muscle

THE MID-INTESTINE

The mid-intestine or ventriculus is an elongate tube, a little longer than the body of the insect itself, and is almost uniform throughout, (Fig 1) It is characterized principally by the numerous crypts or diverticula of the stomach wall, by the absence of a chitinous intima, and by the presence of large secretive epithelial cells, (Fig 4)

Peritropic Membrane—In the ventriculus of *Passalus* the secretion of digestive fluids by the epithelial cells forms a granular layer Its inner border usually forms, as shown by cross-sections, a distinct dark staining line known as the peritropic membrane In places it can be seen that the entire mass separates from the epithelial cells The usual explanation given is that this process continues indefinitely and the peritropic membrane shrinks around the food in the lumen of the gut, while new membranes are repeatedly being formed by the discharging epithelial cells The peritropic membrane extends from the oesophageal valve at the anterior end of the ventriculus into the hind-intestine to about the middle of the proximal portion of the ileum

The epithelium of the ventriculus forms the layer of cells whose function it is to secrete the digestive fluids into the lumen of the gut In *Passalus* we find a very specialized condition for, apparently, secretion is both holocrine and merocrine It is holocrine in the epithelium of the central canal and merocrine in the epithelial cells at the bottom of the crypts

Commonly the wall of the ventriculus of beetles is evaginated to form crypts or diverticula which increase the digestive surface This holds true in *Passalus* and a single cross-section near the center of the ventriculus shows about sixty of these crypts, (Fig 4) At the bottom of each crypt are broad epithelial cells, each connected to a common opening by a short canal Each canal is lined by a dense layer of dark staining substance which is known as the *striated border* As pointed out above, the type of secretion from these epithelial cells is merocrine

In the neck of each crypt the epithelial cells are of a different nature, being elongate and turgid appearing. This type of cell completely lines the central canal of the ventriculus Secretion is holocrine, that is, the entire cell contents are discharged into the lumen of the gut, and the discharged cells are replaced from embryonic nests of "nidi"

From a few of the crypts in the wall of the ventriculus are gland-like appearing evaginations. They are densely filled with dark staining nuclei. The nature and function of these nuclear crypts is undetermined, (Fig 5). The basement membrane of the ventriculus is present.

The circular muscles form two distinct layers. The first is very thin and is composed of fibers circling the central tract of the ventriculus, but they do not extend over the crypts. They frequently run obliquely and cross each other in an irregular manner. The second layer of circular muscles forms a thin incomplete layer on top of the crypts in a twisted fashion.

The longitudinal muscles of the ventriculus are small and isolated among the fibers of the second layer of circular muscles.

The wall of the crypts apparently contains no muscular layers, but is covered by a peritoneal membrane of connective tissue.

THE TRANSITION FROM THE MID-INTESTINE TO THE HIND-INTESTINE

The hind-intestine is set aside from the mid-intestine by a fold of tissue called the pyloric valve. In *Passalus* this is not a true valve in the sense that it closes the tract at this point, but it is a fold of tissue marking the transition from the mid-intestine to the hind-intestine. The size of this fold is so small in comparison to the width of the tract at this point that it could have little significance as a valve in closing the tract. However, since there are two distinct folds, one immediately following the other, it is here considered as the pyloric valve.

The Pyloric Valve—Sections from several different beetles showed the form of the folds to vary considerably, but the anterior fold is always much smaller than the posterior one. The intima first appears at the beginning of the anterior fold and is smooth over the entire valve. The epithelial cells are elongate and regular. Fibers of longitudinal muscles extend into the folds, (Fig 7).

The peritropic membrane is continuous from the mid-intestine into the proximal portion of the ileum.

The intima of the hind-intestine appears on the anterior fold of the valve and both primary and secondary intima are clearly evident. The primary intima is smooth over the folds of the valve, but in the ileum is covered by posteriorly projecting spines.

The epithelium is continuous from the mid-intestine to the hind-intestine. The digestive epithelial cells cease abruptly at the point of the beginning of the first fold of the valve and the point where the intima of the hind-intestine begins. In the valve the cells appear elongate and regular, whereas in the ileum they are cuboidal and irregular. The basement membrane is continuous from the mid-intestine to the hind-intestine.

The circular muscles appear as being continuous from the mid-intestine to the hind-intestine. With the beginning of the valve there appears an additional set of circular muscles lying between the epithelium and the longitudinal muscles. Thus in this region there appears three layers of muscles which are a layer of inner large circular muscles, a layer of longitudinal muscles and a layer of outer smaller circular muscles occurring as isolated strands in the longitudinal layer.

The longitudinal muscles appear as a thin continuous layer from the mid-intestine to the hind-intestine. Fibers extend into the folds of the valve.

THE HIND-INTESTINE

The first division of the hind-intestine may be divided morphologically into two parts, the proximal and distal portions of the ileum. The proximal portion extends from the beginning of the hind intestine to the beginning of the intestinal coecum. The distal region composes the remainder of the ileum and is characterized by large folds in the wall which harbor the intestinal fungi, (Fig 1)

The Proximal Portion of the Ileum — The primary intima is evident from the beginning of the folds of the pyloric valve. It is smooth over the valve and then gradually becomes roughened so that posteriorly projecting teeth are developed. The secondary intima is much thicker than the primary intima, is almost transparent, and shows little difference in the two divisions of the ileum.

The epithelial cells are cuboidal and irregular. The basement membrane is clearly evident.

The circular muscles of the proximal portion of the ileum are largely confined to a layer between the epithelium and the incomplete layer of longitudinal muscles. The layer becomes gradually thicker towards the distal portion of the ileum. The muscles are much larger than those of the mid-intestine, (Fig 7)

The longitudinal muscles are evident as a thin incomplete layer on top of the circular muscles. These disappear entirely at about the point of the beginning of the intestinal coecum.

The Distal Portion of the Ileum—The wall of this part of the ileum is folded to form six series of about twenty chambers, (Fig 10). It is in these chambers that the intestinal fungi are found, though a few are wound around the spines found throughout this region of the ileum. The particles of chewed up wood are mainly confined to the central canal and are not found in the bottoms of the chambers.

The intima is covered by numerous long sharp spines, except in the bottoms of the chambers. Here the intima is merely roughened. The secondary intima is much the same throughout and appears slightly granular and almost transparent, (Fig 12).

The epithelial cells are irregular, cuboidal, and about the same thickness as the secondary intima. A basement membrane is present.

A layer of circular muscles covers the epithelial cells and forms a complete layer several strands in thickness.

Longitudinal muscles are absent in the distal portion of the ileum.

The intestinal coecum is an enlargement of one of the intestinal folds characteristic of the distal portion of the ileum, (Fig 1). In histological structure it is the same as that of the distal portion of the ileum.

TRANSITION FROM ILEUM TO COLON

In the region of the transition from the ileum to the colon there is a fold in the wall of the tract which is considered as the intestinal valve, (Fig 8). In all of the beetles sectioned, the fold was always retracted and whether it can be extended to close the tract at this point was not determined.

The intima in the fold is smooth and lacks the chitinous spines which cover the intima of the main tract. Otherwise there is no difference in the intima, epithelium, and basement membrane which are concerned in the fold. The spines gradually become shorter and disappear entirely a short distance past the valve. Over the fold there are no circular muscles which are characteristic of this region, but instead there is a heavy layer of longitudinal muscles.

The epithelial cells are much the same as in the ileum, except that they gradually become larger and at the point where the circular muscles disappear become more regular and elongate

The layer of circular muscles becomes smaller and disappears entirely a short distance past the intestinal valve. The epithelium at this point is covered only by a peritoneal membrane

Colon—The intima in the colon is smooth and somewhat thinner than in the ileum. The primary intima is a thin dark staining layer, while the secondary intima is a thicker and almost transparent layer, (Fig 6)

The epithelial cells are comparatively regular and elongate. Through most of the colon the wall of the tract is largely epithelium. Towards the distal end the cells become larger, more elongate, and more regular. Nuclei show clearly throughout. At the distal end the wall of the tract is thrown up into six divisions corresponding to the six divisions of the muscles of the colon, (Fig 9). A basement membrane is present.

Circular muscles are not present in the colon.

Longitudinal muscles are not present at the beginning of the colon, but appear later. They gradually become larger and larger, forming an almost complete covering around the tract. They disappear entirely at the end of the colon.

Rectum—The intima of the rectum is thrown into six folds which at one point almost close the lumen of the gut. The intima is distinct and slightly roughened, but not covered by spines, (Fig 13).

The epithelial cells are irregular and cuboidal and pile up on each other in the folds. The nuclei are clear and distinct. The cells are several times smaller than the epithelial cells of the colon.

The circular muscles of the rectum appear as a distinct thick layer. The change from the colon to the rectum is very abrupt. The longitudinal muscles disappear and there arises immediately a heavy layer of circular muscles, (Fig 14). In a short distance the musculature reaches its greatest development and gradually tapers off to the anus. The muscles are divided into six regions by six radial connective tissue (?) septa, (Fig 13).

Longitudinal muscles are absent in the rectum.

MALPIGHIAN TUBULES

In the adult beetle there are four Malpighian tubules which are long and thread-like. Each is attached to the alimentary canal at a single place which is at the point of transition from the mid- to the hind-intestine. The two dorsal tubes are evident in a dorsal dissection passing caudad and disappearing under a fold of the stomach. The two ventral tubes pass under the same fold of the stomach and the four tubes come in contact with the colon at about half way from the ileum to the rectum. They appear on the colon as a maze of convoluted tubes and eventually two of them extend along the posterior portion of the colon where they end blindly in the body cavity attached to tracheae. The other two tubes extend forward and cross to the stomach, forming a mass of convoluted tubes. They extend along the anterior portion of the stomach, where they end blindly in the body cavity.

Histologically the layers of the wall in the Malpighian tubules are the same as in the rest of the hind-intestine. The intima is very thin and irregular. The epithelium consists of irregular cuboidal cells which constitute the greater part of the wall. A basement membrane is present and the muscular layers are absent.

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EXPLANATION OF PLATES

PLATE I

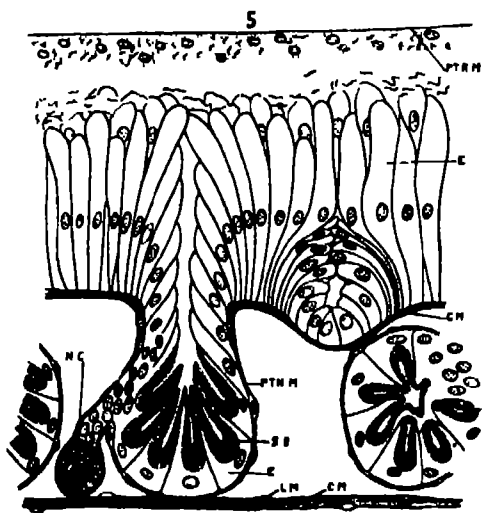
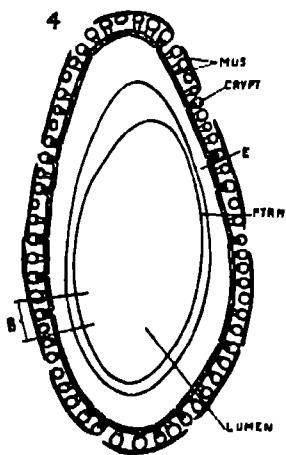
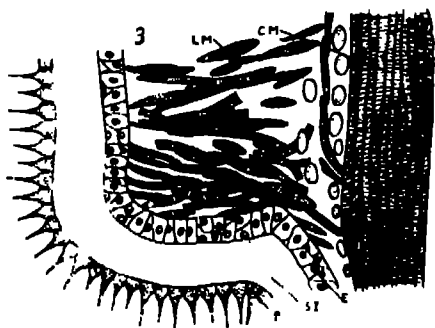
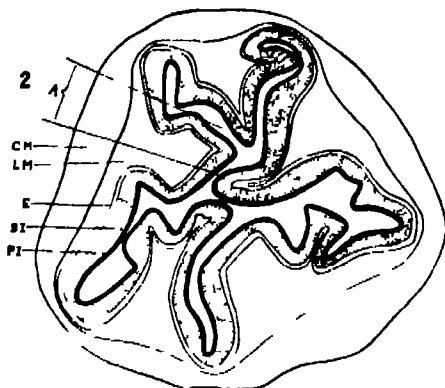
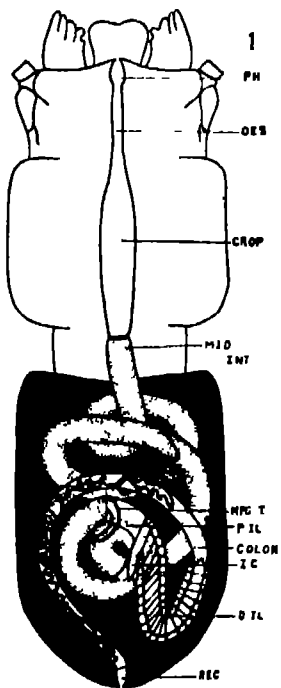
- Fig 1 Dorsal view of adult *Passalus* showing alimentary canal
Fig 2 Cross section of Oesophagus
Fig 3 Section 'A' of Fig 2 enlarged
Fig 4 Cross-section through central part of mid-intestine
Fig 5 Section 'B' of Fig 4 enlarged

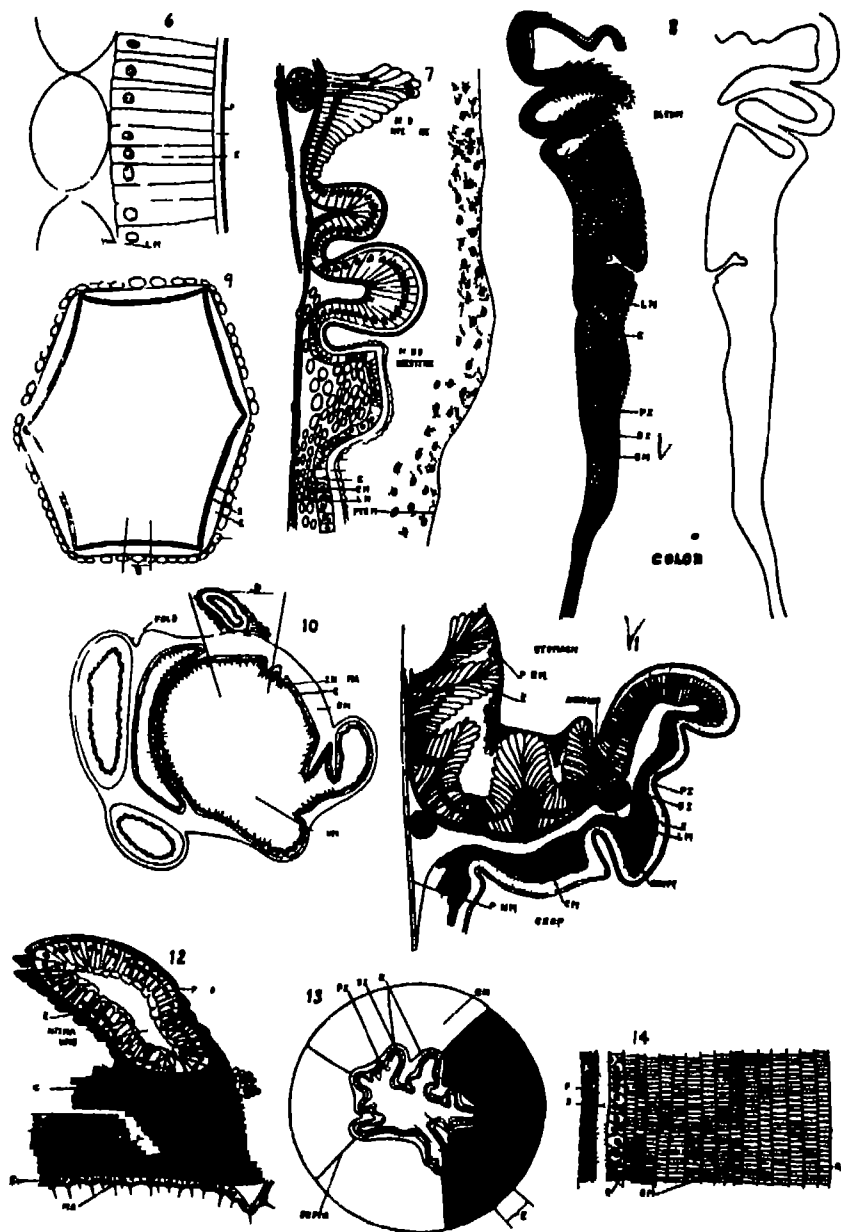
PLATE II

- Fig 6 Section 'C' of Fig 9 enlarged
Fig 7 Longitudinal section through pyloric valve
Fig 8 Longitudinal section through intestinal valve
Fig 9 Cross section of colon near posterior end
Fig 10 Cross-section of distal portion of ileum
Fig 11 Longitudinal section of oesophageal valve
Fig 12 Section 'D' of Fig 10 enlarged
Fig 13 Cross-section of rectum
Fig 14 Section 'E' of Fig 13 enlarged

ABBREVIATIONS USED IN THE FIGURES

- | | |
|--------------------------|---------------------------|
| PH—Pharynx | L M—Longitudinal muscle |
| OES—Oesophagus | E—Epithelium |
| MID INT—Mid intestine | S I—Secondary intima |
| MPG T—Malpighian tubules | P I—Primary intima |
| P IL—Proximal ileum | MUS—Muscle |
| I C—Intestinal coecum | PTR M—Peritropic membrane |
| D IL—Distal ileum | PTN M—Peritoneal membrane |
| REC—Rectum | S B—Striated border |
| C M—Circular muscle | N C—Nuclear crypt |





GLASS SANDS OF OHIO

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AGE OF GLASS SAND ROCKS

The sands of Ohio that have been used for glass making or are now so used range in age from the Devonian to the Pennsylvanian. The following section shows more definitely the principal horizons

Pennsylvanian system	{ Allegheny formation Pottsville formation
Mississippian system	{ Logan formation Black Hand formation
Devonian system	Sylvania sandstone

SPECIFICATIONS FOR GLASS SANDS

The American Ceramic Society has tentatively set specifications for glass sand, and while these include a number of items the most important by far is the chemical composition. The specifications on this point follow *

PERCENTAGE COMPOSITION OF SANDS OF VARIOUS QUALITIES
(BASED ON IGNITED SAMPLES)

QUALITIES	SiO ₂ Min	Al ₂ O ₃ Max	Fe ₂ O ₃ Max	CaO MgO Max
First quality optical glass	99.8	0.1	.02	0.1
Second quality flint glass containers tableware	98.5	0.5	.035	0.2
Third quality flint glass	95.0	4.0	.035	0.5
Fourth quality sheet glass rolled and polished plate	98.5	0.5	.06	0.5
Fifth quality sheet glass rolled and polished plate	95.0	4.0	.06	0.5
Sixth quality green glass containers and window glass	98.0	0.5	0.3	0.5
Seventh quality green glass	95.0	4.0	0.3	0.5
Eighth quality amber glass containers	98.0	0.5	1.0	0.5
Ninth quality amber	95.0	4.0	1.0	0.5

*Am Cer Soc, Vol 6, No 6, p 182

PRODUCTION OF GLASS SAND IN OHIO FOR CERTAIN YEARS

	Short Tons	Value
1902	42 311	\$ 50 428
1903	70 460	70 999
1910	139 122	104,295
1913	55,844	139,220
1923	46,184	101 362

In 1923 there were 2,034,958 short tons of glass sands produced in the United States with a value of \$3,751,788 Ohio's contribution to the output for that year was therefore only a little more than 2 per cent in weight and less than that in value

LOCATION AND QUALITY OF OHIO GLASS SANDS

Ohio has enormous quantities of sandstone, but as is shown on later pages its composition is not suitable for glass, except for common products where color is not objectionable Iron is the chief trouble maker Alumina is always present, but this in itself is not objectionable In fact some glass makers add alumina, which is said to increase the toughness of glass Calcium and magnesium oxide also are almost always present, but they do little or no harm if their proportion is fairly constant However, in one locality in Ohio they range from 6 to 18 per cent of the rock, with of course a corresponding variation in the silica Titanium oxide also is present, but its proportion is commonly less than one-fourth of one per cent It, too, gives color and therefore is objectionable except in the most common varieties of glass

These impurities can be reduced by washing Thus in 42 samples the content of iron oxide averaged 0.35 per cent and after washing 0.18 per cent, a decrease of 49 per cent In like manner the titanium oxide was reduced 57 per cent and the alumina 67 per cent It should be stated that the chemical analyses which form so important a part of this paper were made in the laboratory of Professor D J Demorest

In the following pages the principal deposits of sandstone in the State are reviewed Those lowest in the geological time scale are first considered then the next lowest, and so on

SANDS OF DEVONIAN AGE

The Monroe limestone forms the surface of several thousand square miles in western Ohio In Lucas County it consists of three principal divisions

Detroit River dolomite	} <i>Devonian</i> {	120 feet
Sylvania sandstone		40 feet
Bass Island dolomite	<i>Silurian</i>	

Only the Sylvania sandstone concerns us in this paper. It can be traced as a narrow band from the Ohio-Michigan State line south to Otsego Falls of the Maumee. Beyond that its position is below drainage and data concerning it are therefore lacking. While the sandstone has been quarried at several places in Lucas County, the best known deposit is that at Silica, two and one-half miles south of the State line.

Silica—In 1914 the Owens Bottle Machine Company purchased the plant of the Toledo Silica Sand Co., at Silica, Lucas County. When this quarry was first opened is unknown, but sand was gotten here as early as 1863 and shipped to Pittsburgh, where it was used for making flint glass*. Since that time the rock has been quarried at irregular periods.

When visited in 1917, from 16 to 24 feet of sandstone was being quarried, but the core drill is reported to have shown a maximum thickness of 60 feet†. The beds dip sharply to the west so that the outcrop is narrow. In general the sandstone is poorly cemented with calcite or dolomite and has a light-gray color. The beds range from a few inches to several feet in thickness and are irregular. Bottles and window glass have been the principal products in the glass line.

Chemical Analysis

	Rock Chips from Quarry Face	Glass Sand Washed
Silica, SiO_2	90.73	95.11
Alumina, Al_2O_3	76	13
Ferric oxide	06	02
Calcium carbonate, CaCO_3	5.00	3.05
Magnesium carbonate, MgCO_3	3.18	1.42
Titanium oxide, TiO_2	00	00
Loss on ignition	30	25

The company reports the silica to range from 88 to 96 per cent and the calcium and magnesium carbonates from 6 to 18 per cent. The iron is low, but the varying proportion of silica and the rapidly changing calcium and magnesium make the sand unsatisfactory. No sand has been used from this quarry for glass making since 1920 and the large and well equipped plant has been dismantled.

*Geol. Survey Ohio, Vol. I, p. 582.

†Prof. J. E. Carman, who has made a detailed study of this region, gives the thickness of the sandstone as 40 feet.

SANDS OF MISSISSIPPIAN AGE

The Mississippian rocks of Ohio consist of shales, sandstones, conglomerates, and limestone. They outcrop as a broad belt from Ashtabula and Trumbull counties west to the middle of the State and thence due south to the Ohio River, where the rocks cross into Kentucky. The only Mississippian rocks that have been used for glass making lie near the top and include the Black Hand and the Logan formations.

Millwood—On the south side of the Kokosing River, near the village of Millwood, in the eastern part of Knox County, a sandstone of Mississippian age (probably the Black Hand) has been worked since 1906 for glass and molding sand. The rock which is worked to a depth of 22 feet lies in thin, uneven layers except near the base, where a bed of 3 or 4 feet thick was noted. As a whole, the rock is poorly cemented and hence easily crushed. On the east side of the quarry and part of the south the rock has a light buff color, but on the west side and part of the south it is light gray. The latter is or has been used at Mt. Vernon, Columbus, and Coshocton for glass making, and is now used by the Pittsburgh Plate Glass Co., at Mt. Vernon, for window glass. The buff sand finds a market for steel castings. The sand is also employed in making water glass, and for water filters. Columbus, Lima, Delaware, Struthers, Toronto, and Flint, Michigan, were supplied for the latter purpose. It is claimed that on the north side of the river there is 30 feet of light-colored sand. The operating company is the Knox White Sand Co.

Chips were taken of the gray sandstone from the west end of the quarry and from ledges exposed along the Kokosing, and on analysis gave the following results:

	Chips from West End of Quarry Percent	Chips from Bluffs of Kokosing Percent
Silica, SiO_2	98.60	97.63
Alumina, Al_2O_3	18	50
Ferric oxide	09	22
Calcium oxide, CaO	02	00
Magnesium oxide, MgO	08	01
Titanium oxide, TiO_2	03	04
Loss on ignition	21	70
	<hr/> 99.19	<hr/> 99.19

After laboratory washing the first sample had its ferric oxide reduced to 07 per cent and the second to 14 per cent

Microscopical examination of the first sample showed the following minerals which are listed in order of their abundance quartz, kaolin, muscovite, limonite, zircon, sericite, hematite, rutile, and chlorite In the second sample feldspars are listed in abundance after silica, due probably to less weathering than in the first sample

Plant of the E H Everett Co This plant is located at Black Hand rock on the Licking River in the eastern part of Licking County It has been operated since about 1890 and the product goes to the plant of the American Bottle Co, at Newark, where it is used for making bottles for beverage purposes A section in the quarry is given below

Mantle rock	4 ft
Logan formation Thin bedded, coarse grained sand stones Rejected	21
Black Hand formation Thick bedded, coarse-grained sandstone, pebbly in places Buff colored	60

The sand is crushed, screened, and washed, and then thrown on the stock pile The iron content varies In places it is barely sufficient to impart a buff color, but occasionally it forms crusts of siliceous ore In places thin shale or clay layers are found No carbonaceous matter was observed The composition of the sand is shown by the following analyses

	Unwashed Sand	Washed Sand	Washings
Silica, SiO ₂	97 05	98 80	65 80
Alumina Al ₂ O ₃	1 50	12	16 60
Ferric oxide	79	52	5 71
Calcium oxide CaO	00	00	42
Magnesium oxide MgO	00	00	25
Titanium oxide, TiO ₂	18	10	1 10
Loss on ignition	40	22	6 30

The washed sand was examined with a microscope and the following minerals identified They are listed in order of their abundance Quartz, orthoclase, plagioclase, microcline, tourmaline, limonite, sericite, kaolinite, magnetite, chlorite, rutile, zircon, and monazite

When working in full the quarry produces approximately 250 tons per day, but the average is only one-half of that

Rockbridge—About 2 miles south from Rockbridge, Hocking County, the Black Hand formation was formerly worked for

glass and molding sand When visited the quarry face had a maximum height of 60 feet and a length of 250 feet The rock is coarse grained and has two layers of pebbles, each about 2 feet thick, and lying from 12 to 16 feet apart At the north end of the quarry one of these thickens to 9 feet Occasional quartz pebbles were found scattered through the mass of rock At the top and bottom of the quarry the rock has a buff color, but below the pebbly layers it is light gray Throughout the mass are spots or patches of darker color, due to concentration of iron

This rock was crushed in a gyratory crusher and further reduced in a wet pan It was then run through a revolving wheel screen and an auger washer, and transported to the stock pile for draining Later it was passed through a drier and screened again

Three grades of sand were produced The best was a pure white that was obtained from beneath the pebbles It was used in making window glass The second grade was also a glass sand, but less pure than the first However, much of the second grade was disposed of to steel mills and to brick plants The third grade had its source in the colored rock and was used for sanding steel rails in coal mines and on traction lines The pebbles, which are highly objectionable in glass sand, were carefully screened and sold to clean steel and iron castings Two samples gave the following analyses

	Puro Glass Sand Washed	Glass Sand Washed
Silica SiO_2	98 63	98 73
Alumina Al_2O_3	44	45
Ferric oxide	13	46
Calcium oxide, CaO	00	00
Magnesium oxide, MgO	03	00
Titanium oxide TiO_2	25	13
Loss on ignition	20	22
	<hr/> 99 68	<hr/> 99 99

Microscopic examination of the first sample showed the presence of the following minerals, which are listed in order of their abundance Quartz, kaolinite, tourmaline, zircon, limonite, magnetite, apatite, and rutile In the second sample limonite and hematite rank third and fourth in abundance

A fire destroyed the plant in 1915 and it was then abandoned

SANDS OF PENNSYLVANIAN AGE

Rocks of Pennsylvanian age extend from the Ohio-Pennsylvania line southwest to the Ohio River and cover a large part of the eastern third of the State. They include coal, clay, shale, sandstone, conglomerate, and limestone.

Only the two lower formations, Pottsville and Allegheny, have been sources of glass sand and of these the Pottsville is the more important. The basal member is the Sharon conglomerate, which in places is pebbly and elsewhere a coarse sandstone or even a shale. The rock is massive and poorly cemented.

The pebbles are of quartz and vary in size from a small fraction of an inch to 3 inches or more. The color is of light shades. Near the top, buff is the common color of the rock, but below, where weathering has been less, gray is the usual shade.

The Sharon varies greatly in thickness. Lamb places the maximum in northern Ohio at 90 feet and Stout* that for the southern part of the State at 200 feet. Thicknesses of 50 feet are common. At present this sand is used in a small way for window glass and bottles.

The Allegheny formation has deposits of sandstone, but they are much thinner than the Sharon conglomerate. Nearly everywhere they are high in iron and therefore unsuited for glass except perhaps the most common wares. In Tuscarawas County rock of this age is quarried for steel molding sand.

Hartford —The plant of the Standard Silica Co. is located one and one-half miles west of Hartford, Trumbull County, on the western margin of a ridge of the Sharon conglomerate. A maximum of 30 feet of the rock was quarried. The upper 6 to 8 feet is decidedly pebbly, below this the rock is a coarse sandstone. The color ranges from buff to gray. Small grains of coal are scattered through the rock.

The rock was loaded on cars with a steam shovel, was crushed, screened, washed, and dried. For several years this sand had a market for the manufacture of glass fruit jars. Other uses were for molding sand and for concrete.

This plant began shipping sand in December, 1910, it was closed in March, 1921. High freight rates are reported to have been the principal reason for closing the works.

*This Journal, Vol 21 p 252

National Sand and Stone Company—The plant of this company is located in Mahoning County about 2 miles south of Mineral Ridge. The rock is a coarse sandstone, the lower 3 feet in places conglomeratic, and lies at or near the base of the Pennsylvanian. Specks and even small pockets of coal are occasionally found, one was noted which measured 5 inches in thickness. As much as 43 feet of sandstone has been quarried. The top 10 feet is in beds usually less than 12 inches thick, but the rest of the quarry is more massive and beds measuring 10 feet were found. The rock is friable and therefore easily crushed. The upper two-thirds of the stone has a buff or yellow color, and that below gray, the difference being due to weathering. The buff stone is crushed and washed and disposed of for foundry purposes, for brick making, and on traction rails to prevent slipping.

The gray stone is crushed in a jaw crusher, ground in a wet pan, washed, screened, and dried. In washing, 6 tons of water is said to be used for each ton of sand. Glass is the chief use of this product and the market is said to extend from Cleveland to Washington, Pa. The proprietor stated that the General Electric Co finds this sand satisfactory for making electric light bulbs. It has also been used in making various grades of bottles and window glass. Other uses are for water glass and the white coat for plastering.

Following are analyses of two samples of washed glass sand from this plant

Silica SiO_2	99.33	98.31
Alumina Al_2O_3	10	39
Ferric oxide	009	31
Calcium oxide CaO	07	09
Magnesium oxide, MgO	05	04
Titanium oxide, TiO_2	09	08
Loss on ignition	15	26
	99.799	99.48

Massillon—At Massillon, Stark County, is the Everhard quarry, which was opened in 1884. Its main products have been steel molding sand, furnace sand, core sand, building stone, and to a much smaller extent glass sand.

The beds worked are coarse grained, and have a maximum thickness of 60 feet. The rock is friable and shelly near the top, but thicker below. In fact, beds 10 feet thick and without a horizontal break were noted. The color is buff, but in a

quarry a little farther west it is light brown, called pink by the workmen

Selected chips from the quarry face had the following composition

	Percent
Silica, SiO_2	96 51
Alumina, Al_2O_3	1 90
Ferric oxide	58
Calcium oxide, CaO	07
Magnesium oxide, MgO	01
Titanium oxide, TiO_2	12
Loss on ignition	56
	<hr/> 99 75

A sample collected in the same manner was examined with a microscope and the following minerals noted They are listed in the order of their abundance Quartz, limonite, kaolinite, feldspars, muscovite, hematite, sericite, zircon, and magnetite

DUNDEE SANDSTONE

The Dundee sandstone lies near the base of the Allegheny formation It is well exposed along the valley of Sugar Creek in the northwest corner of Tuscarawas County, where it is worked in a large way at Barrs Mills, Dundee, and Beach City for steel molding purposes and furnace bottoms, and to a much smaller extent for glass sand The rock is coarse grained, but is without pebbles, and has a color which ranges from gray to buff, the latter predominating Fifty feet or more of the rock is quarried

The composition of the sand along Sugar Creek Valley is shown below

	Massillon Sand & Stone Co Unwashed Barrs Mills	National Malleable Castings Co Unwashed Dundee	Beach City Silica Sand Co Unwashed
Silica, SiO_2	98 28	96 63	97 76
Alumina Al_2O_3	32	2 00	69
Ferric oxide	24	42	34
Calcium oxide, CaO	00	00	00
Magnesium oxide, MgO	13	04	11
Titanium oxide, TiO_2	07	20	05
Loss on ignition	32	60	40 -

A sample of the stone from Barrs Mills was examined with the microscope, and the following minerals noted In order of their abundance they are, quartz, microcline, feldspars, limonite, kaolinite, tourmaline, chlorite, zircon, titanite, and serpentine

Barberton —The plant of the Summit Silica Co is located near the southern border of Barberton, Summit County, where a ledge of the Sharon conglomerate, 45 feet high, is the basis of the industry. In places the pebbles are confined to part of the ledge, while elsewhere they occur through the mass. The company estimates that 60 per cent of the rock is pebbly. Most of the pebbles are less than one inch in diameter and the largest observed measured about 3 inches. They are of quartz and have various shades of light colors.

The rock is crushed and washed, and that used for glass making is dried and screened. However, only the sandy part of the rock is marketed for glass making. In other words, the crushed pebbles are not used for that purpose. The sand is suitable for window glass, bottles, and in fact any kind of glass except the higher grades.

Following is an analysis of a sand from this plant

	Unwashed and Unscreened Sand Percent
Silica, SiO_2	97.41
Alumina, Al_2O_3	58
Ferric oxide	31
Calcium oxide, CaO	11
Magnesium oxide, MgO	00
Titanium oxide, TiO_2	09
Sodium oxide, Na_2O	04
Potassium oxide, K_2O	08
Loss on ignition	44
	<hr/> 99.06

Microscopical examination of the first sample showed the following minerals which are listed in order of their abundance: Quartz, magnetite, zircon, kaolinite, feldspar, muscovite, and apatite.

Chalfants —The Chalfants plant of the Central Silica Co is situated in the northern part of Perry County, and has been in existence for more than 40 years. The rock worked is the Pottsville conglomerate, and is covered with from 4 to 6 feet of stripping, which is removed with a drag line system. Beneath the stripping, the stone is worked to a depth of 35 feet. It is coarse-grained sandstone and in places contains quartz pebbles. Near the top the rock is shelly, farther down the layers are thicker, while near the base of the quarry the rock is massive. The material is poorly cemented and its color varies from buff to light brown. The rock is loaded onto cars with a steam shovel, and is hauled to the mill by a dinky engine.

The rock is broken in a gyratory crusher and is further reduced in a dry pan. It is then run through a 6-mesh rotary screen and the material which passes through it is washed and dried. Again this sand is screened, first through a 20-mesh and then through a 16-mesh. What passes through the latter is disposed of in large part for green and amber bottles and for window glass. When the plant is working to capacity this amounts to 80 tons per day or about 48 per cent of the output.

Jackson County—Sandstone was formerly quarried on the J. S. McKitterick farm, one mile north of Jackson, for bottle glass, but when the plant at Jackson was closed the one market for this glass sand was at an end.

The sandstone, of which a ledge of 60 feet is exposed, lies on or near the horizon of the No. 1 coal. It is coarse grained and poorly cemented. The color varies from gray to brown. No mill was erected, the rock being crushed with hammers by hand labor.

The Ohio Flint and Glass Sand Co.—The quarry of this company is located on the Jasper Middaugh farm in the southwest corner of Section 25, Reading Township, Perry County. The rock lies at an elevation of about 1,080 feet and while its position in the rock column has not been accurately determined, it appears to lie in the Allegheny formation, or lower coal measures.

The sandstone which is covered with about 2 feet of mantle rock has been quarried to a depth of 18 feet, and it is reported that the drill showed 14 feet of sandstone below this. Near the top the rock is thin-bedded, but the layers increase in thickness below. The sandstone is coarse grained and poorly cemented. White mica or muscovite is common. The color varies from light gray to buff. Other knobs in this locality carry the sandstone.

Analyses

	Washed Sand	Chips from Quarry Face
Silica SiO_2	98.01	94.23
Iron oxide Fe_2O_3	29	34
Alumina Al_2O_3	35	2.98
Titanium oxide, TiO_2	20	28
Phosphorus pentoxide, P_2O_5	02	02
Calcium oxide CaO	14	20
Magnesium oxide MgO	34	22
Sodium oxide, Na_2O	16	11
Potassium oxide, K_2O	24	86
Ignition loss	45	1.00

The rock is trucked to Rushville Station, where it is crushed, screened, washed, and dried. It is claimed that in washing the sand loses much of its color. For some months the plant is idle because the roads are such that trucking can not be done. At present (1924) the company is considering the erection of an aerial tramway from quarry to mill. The sand has been used by the Hazel Atlas Glass Co., at Zanesville.

COMPOSITION OF OHIO SANDS

	Silica SiO_2	Alumina Al_2O_3	Ferric Oxide	Calcium Oxide CaO	Magnesium Oxide MgO	Titanium Oxide TiO_2	Loss on Ignition
<i>Athens County</i>							
Palos (Mahoning sandstone Conemaugh formation)							
Chips from fresh surface	89.88	6.01	82	00	12	12	1.12
<i>Carroll County</i>							
Craig Stone Co. (Conemaugh formation)							
Chips from fresh surface	94.91	2.80	54	00	.04	15	90
Prosperity Quarry (Conemaugh formation)							
Chips from fresh surface	95.92	2.31	36	00	05	12	90
<i>Columbiana County</i>							
Jessup Quarry, Salem (Allegheny formation)							
Rock crushed but unwashed	85.14	6.08	3.66	10	13	25	2.65
O Mara Quarry, Lisbon (Allegheny formation)							
Chips from rock face	94.30	2.97	58	00	15	15	1.10
<i>Coshocton County</i>							
Chips from ledge near Chili (Allegheny formation)	96.24		45	00	04		58
Layland Sand & Stone Co. (Pottsville formation)							
Chips from quarry face	95.20	2.30	45	00	10	10	66
Moore Quarry, Warsaw (Pottsville formation)							
Chips from quarry face	92.66	3.92	50	00	01	15	70
<i>Cuyahoga County</i>							
Berea sandstone at Berea							
Chips of rock and sand from grind stone plant	01.78 93.13	4.12 3.86	84 65	11 19	04 25	24	1.19 1.43
Berea sandstone, Berea							

COMPOSITION OF OHIO SANDS—CONTINUED

	Silica, SiO ₂	Alumina Al ₂ O ₃	Ferric Oxide	Calcium Oxide CaO	Magnesium Oxide MgO	Titanium Oxide TiO	Loss on Ignition
<i>Fairfield County</i>							
Allegheny Quarry, 4 miles east of Lancaster (Black Hand and Logan formations)							
Chips from fresh surface of quarry	96 03	1 34	02	00	13	25	55
Sharp Quarry, Sugar Grove (Black Hand formation)							
Clean chips from spalls	97 43	51	58	00	10	00	41
<i>Gallia County</i>							
Fitzpatrick farm near Alice (Conemaugh formation)							
Chips from face of ledge, unwashed	93 07	3 71	42	02	03	12	80
Same, but washed	95 43	1 85	37	00	03	12	40
<i>Harrison County</i>							
Ozark Quarry (Conemaugh formation)							
Chips from quarry face	93 56	4 04	60	00	03	13	1 15
<i>Hocking County</i>							
Rockbridge Quarry of Central Silica Co (Black Hand formation)							
Glass sand, washed	98 63	44	13	00	03	25	20
Glass sand, washed	98 73	45	46	00	00	13	22
<i>Holmes County</i>							
Uhl Quarry, near Killbuck (Pottsville formation)							
Purest rock	97 41	65	12	12	00	07	27
White rock	97 06	1 30	15	01	06	15	25
Less pure rock	96 48	1 44	20	00	04	13	30
Glenmont Quarry (Pottsville formation)							
Chips from quarry face	95 24	2 55	38	07	00	28	43
Columbus Co Quarry (Pottsville formation)							
Chips from quarry face	96 30	1 88	42	00	03	12	60
Gray Quarry near Hardy's Switch (Pottsville formation)							
Chips from quarry face	94 25	3 17	63	01	00	15	61
<i>Jefferson County</i>							
Quarry on Champion and Duffy farms (Conemaugh formation)							
Chips from quarry face	84 42	8 08	2 50	04	01	51	2 10
<i>Knox County</i>							
Millwood White Sand Co (Logan (?) sandstone)							
Glass sand, unwashed	98 60	18	09	02	06	03	21
Molding sand washed	98 29	15	28	03	06	03	23
Chips from ledges along the Kokosing	97 63	59	22	00	01	04	70

COMPOSITION OF OHIO SANDS—CONTINUED

	Silica SiO ₂	Alumina, Al ₂ O ₃	Ferric Oxide	Calcium Oxide CaO	Magnesium Oxide MgO	Titanium Oxide TiO ₂	Loss on Ignition
<i>Jackson County</i>							
Jackson Sand Mining Co., 2 miles north of Coalton (Pottsville formation)							
Bin sample top sand unwashed	96 79	2 00	20	00	08	17	55
Bin sample bottom sand unwashed	96 19	2 22	20	00	03	18	65
Chips from near by ledges	98 50	70	22	10	00	10	35
Buzzard Rocks cliff							
Chips from quarry face	98 60	45	37	10	00	05	30
<i>Lawrence County</i>							
Wallenfelsz and Williams farm, north of Ironton (Pottsville formation)							
Chips from quarry face	91 09	4 80	1 10	00	10	15	92
Petersburg Fire Brick & Tile Co. Coal Grove (Allegheny formation)							
Chips of fire stone	85 57	9 06	42	02	03	34	2 10
Chips of ganister	92 35	4 51	63	00	07	45	1 13
<i>Licking County</i>							
Everett Quarry Toboso (Black Hand formation)							
Glass sand unwashed	97 05	1 50	79	00	00	18	40
Glass sand unwashed	97 11	1 47	72	00	02	18	40
Glass sand washed	98 80	12	52	00	00	10	22
Washings	65 80	16 60	5 71	42	25	1 10	6 90
<i>Lorain County</i>							
Cleveland Stone Co Quarry South Amherst (Berea sandstone)	02 15	3 85	1 40	50	20	40	1 70
<i>Lucas County</i>							
Toledo Silica Sand Co (Monroe forma tion)							
Rock chips from north end of quarry	90 73	76	06	5 00	3 18	00	30
Car sample of sand Washed and screened	95 11	13	02	3 05	1 42	00	25
<i>Mahoning County</i>							
Spencer Quarry, 2 miles south of Ellis- worth (Pottsville or Allegheny formation)							
Chips from quarry face	98 14	45	13	04	02	09	35
National Sand & Stone Co., 2 miles south of Mineral Ridge (Pottsville formation)							
Best glass sand washed	99 33	10	009	07	05	09	15
Glass sand	98 31	39	31	09	04	08	26

COMPOSITION OF OHIO SANDS—CONTINUED

	Silica SiO ₂	Alumina Al ₂ O ₃	Ferric Oxide	Calcium Oxide CaO	Magnesium Oxide MgO	Titanium Oxide TiO ₂	Loss on Ignition
<i>Perry County</i>							
Chalfant Quarry of Central Silica Co (Pottsville formation)							
Glass sand, washed	99 43	18	13	00	05	04	22
Steel sand, washed	95 66	1 84	19	00	16	22	87
Ganister unwashed	98 61	39	20	00	06	20	27
Blast sand, washed	97 90	1 08	22	00	07	08	53
Washed sand from pit of Ohio Flint & Glass Sand Co Reading Township (Allegheny (?) formation)	98 01	35	29	14	34	20	45
Chips of sandstone from face of same quarry	94 23	2 98	34	20	22	28	1 00
<i>Pike County</i>							
Berea sandstone near Waverly	91 00	5 20	1 47	tr	28		1 80
<i>Portage County</i>							
Kent Quarry (Pottsville formation)							
Chips from old quarry face	98 50	28	10	08	02	07	40
Portage Silica Co (Pottsville formation)							
Steel molding sand, washed	98 14	16	35	38	05	08	31
Fine blast sand, washed	98 46	17	23	17	00	03	28
Coarse blast sand, washed	98 04	24	28	21	01	03	30
Very fine washings	92 15	3 10	72	76	06	65	40
<i>Stark County</i>							
Coxey Silica Sand Co, Pauls (Potts- ville formation)							
White steel molding sand, unwashed	96 87	1 58	13	00	03	17	57
Buff steel molding sand, unwashed	95 07	1 95	53	12	00	15	04
Sonnhalter Sand & Stone Co Massillon (Pottsville formation)							
Glass sand, washed	90 77	84	61	02	17	20	52
Rolling mill sand, unwashed	93 63	3 50	80	04	00	23	1 25
Massillon Silica Sand Co (Pottsville formation)							
Finer steel molding sand, unwashed	97 40	1 44	49	11	02	13	52
Coarser steel molding sand, un- washed	97 48	56	32	05	04	07	50
Everhard Co Massillon (Pottsville formation)							
Bottle glass or steel molding sand	95 75	1 60	81	00	02	15	68
Furnace bottom sand	96 29	1 63	33	03	00	20	43
<i>Scioto County</i>							
Damarin Hill Quarry, Portsmouth (Pottsville formation)							
Chips from face of quarry	97 49	1 50	28	00	07	15	51
McDermott Quarry, (Cuyahoga forma- tion)							
Blue gray stone	85 60	7 25	2 60	tr	tr	75	1 70
Yellow stone	84 50	6 35	3 00	tr	tr	75	2 15

COMPOSITION OF OHIO SANDS—CONTINUED

	Silica, SiO ₂	Alumina, Al ₂ O ₃	Ferric Oxide	Calcium Oxide CaO	Magnesium Oxide, MgO	Titanium Oxide TiO ₂	Loss on Ignition
<i>Summit County</i>							
Summit Silica Co., Barberton, (Pottsville formation)							
Sand, unscreened and unwashed	97 41	58	31	11	00	09	44
Emery Sand Plant Twinsburg (Pottsville formation)							
Sand, unwashed	97 74	46	83	00	18	09	34
Akron White Sand Co., Akron (Pottsville formation)							
Sand, unwashed	97 10	1 27	19	00	05	08	55
Newell Quarry, Macedonia (Pottsville formation)							
Chips from lower half of quarry	98 00	36	53	01	08		34
Chips from lower half of quarry	98 29	69	18	00	00	04	28
Bramley Quarry, Copley (Pottsville formation)							
Chips from quarry face	98 54	28	24	01	01	07	29
Boston ledges, Boston Township (Pottsville formation)							
Chips from 50-foot face	97 91	51	44	05	06	05	32
Erle Railroad cut, 2½ miles west of Barberton (Pottsville formation)							
Chips from face of ledge	98 07	2 91	19	14	06	18	46
<i>Trumbull County</i>							
Trumbull Stone & Sand Co., 5 miles west of Warren (Pottsville formation)							
Selected furnace sand, unwashed	97 13	1 52	27	01	03	23	39
Furnace sand, unwashed	95 99	1 97	35	09	00	27	62
<i>Tuscarawas County</i>							
American Sand Co., 1 mile north of Dundee (Pottsville formation)							
Selected steel molding sand, unwashed	97 99		45	00	05		43
Steel molding sand, unwashed	96 00	2 08	31	02	03	18	61
National Malleable Castings Co., Dundee (Pottsville formation)							
Core sand, unwashed	96 10	1 91	33	00	02	26	67
Steel molding sand, unwashed	96 63	2 00	42	00	04	20	60
Beach City Silica Sand Co., (Pottsville formation)							
Steel molding sand from bottom rock	97 76	69	34	00	11	05	40
Steel molding sand from top rock	97 95	1 00	37	00	06	12	35
Dundee Silica Sand Co., Dundee (Pottsville formation)							
Furnace bottom sand, unwashed	94 30	2 85	86	00	04	33	80
Coarse steel molding sand from bottom of quarry	98 76	25	19	00	04	04	40
Selected steel molding sand	97 40	1 13	13	00	02	17	30

COMPOSITION OF OHIO SANDS—CONTINUED

	Silica SiO ₂	Alumina Al ₂ O ₃	Ferric Oxide	Calcium Oxide CaO	Magnesium Oxide MgO	Titanium Oxide TiO ₂	Loss on Ignition
<i>Tuscarawas County—(Continued)</i>							
White Rock Silica Sand Co (Allegheny formation)							
Furnace bottom sand unwashed	98 87	1 20	45	00	06	11	43
Steel molding sand unwashed	96 52	1 83	31	00	03	17	30
Massillon Silica Sand Co Barrs Mills (Pottsville formation)							
Steel molding sand unwashed	98 28	32	24	00	13	07	32
George J Miller farm 1½ miles south west of Newcomerstown (Allegheny formation)							
Fresh chips from outcrop	92 55			03	01		1 15
<i>Vinton County</i>							
Beckley farm, 1½ miles south of Mc Arthur							
Fresh chips from outcrop	94 03	1 24	40	00	08	13	76
<i>Wayne County</i>							
Oliver Silica Sand Co, Warwick (Pottsville formation)							
Steel molding sand unwashed	98 30	80	27	02	05	07	32
Franklin Industrial Co Warwick (Pottsville formation)							
Steel molding sand unwashed	97 47	72	38	00	06	09	60

TYPE AND VENATION OF WINGS AS FACTORS IN SEPARATING CERTAIN DELTOCEPHALOID GENERA

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A few of the *Deltocephaloid* genera of the *Cicadellidae* such as *Deltocephalus*, *Lonatura* and *Aconura** (American forms) are so closely related that specialists working upon this group are puzzled frequently to know just how to separate the species concerned by constant generic characters. Although as in many other groups, the generic standing of certain species is quite easy to determine, other species exhibit characters more common to allied genera. While the writer was engaged in a monographic study of the species of *Deltocephalus*, the question was asked by several co-workers where the line should be drawn between these genera or what character should be used as a final criterion for separation. These genera were therefore given special study from a comparative standpoint and an examination was made of all available material in them. This study has revealed several characters, some of a detailed technical nature. The most conspicuous and outstanding one, however, has to do with wing characters or conditions. These types of wings seem to indicate on the one hand definite relationships among certain species and on the other hand exhibit structural differences between these genera which form a basis for their separation. These genera however, which in the writer's opinion should be considered as generic groups, at least in the making, have apparently not yet diverged sufficiently that hard and fast lines can be drawn to separate them. There is consequently some doubt regarding the generic standing of a few species.

Throughout these genera it is common for many or all species belonging to a genus to have a dimorphic condition in the first pair of wings or elytra. In *Deltocephalus* this condition is lacking in certain subgroups and only the normal wing condition is known, but it is found in all described species of certain

* The genus is considered here as given by Van Duzee in his catalogue of Homoptera, 1916. The true *Aconura* species probably do not occur in North America.

other groups. The short winged condition is usually spoken of as a brachypterous wing and the long winged the macropterous form. All of these species feed upon grasses and the great majority of those containing short winged forms are plains and prairie species. The size of the wing in these species may be of very slight importance so far as their ability to survive is concerned, since very little or no extended locomotion may be necessary in such a habitat.

With reference to this dimorphic wing condition in *Deltocephalus*, one of the most interesting discoveries during this study was the capturing of a male of *D. mendosus* Ball on a prairie adjoining a Florida everglade. This specimen has a right elytron of the macropterous variety and the left wing is a brachypterous form. A photograph of this specimen is inserted in the accompanying plate. Perhaps this might be called a heteromorph. It can scarcely be termed a gynandromorph of the lateral type for all other structures except the wings are normal, especially the genital structures of the male which are typical and normal for that sex and species. It would certainly be necessary to have both sexual structures represented to classify it thus.

In this specimen each of the elytra is typical of the form it represents. That is, in an examination of several hundred specimens of *D. mendosus* and a comparison with this specimen in question, it is found that the right elytron is typical of macropterous individuals and the left elytron is typical of the brachypterous specimens. It is therefore merely this dimorphic wing condition exhibited in a single individual. This example is given as it illustrates the condition of the reduction of the wing in the brachypterous individuals, as this condition occurs throughout the genus *Deltocephalus*. In some species of this genus the elytra are shortened more proportionately, but in all cases each part of the elytron seems to be shortened in proportion to every other part and the cells are merely reduced in size leaving the venation relatively the same.

The greatest reduction probably occurs in the apical portion but in all the material examined consisting of practically all the species of *Deltocephalus* and hundreds of specimens, when reduction occurs there is still a group of apical cells in the brachypterous wing although small in some cases. In an extreme condition of a short winged example of *D. collinus* the outer anteapical and apical cells are combined but this is not typical of

a large series of short winged forms of this species. Even in this extreme case the apical cells are all present with one exception.

In some species of the genus the wing venation will vary in minor respects and is somewhat irregular even in elytra of the same form—brachypterous or macropterous. Especially is this the case where it may be a question of the number of cross veins or the division of certain cells. Even in these instances there is no marked change in the plan or pattern of venation when reduction occurs. A comparison of the right and left elytra in the photograph of *D. mendosus* (Figure 1) will show that the venation in the two elytra is practically the same, except for size, vein for vein and cell for cell. This is the type of wing reduction which is characteristic and almost constant for the species of *Deltocephalus*. Another example shown in Figures 5 and 6 illustrates the long and short winged forms of *D. caperatus* Ball.

In both *Lonatura* and *Aconura* there is also a dimorphic condition of the elytra. As compared with *Deltocephalus* the type of venation in the short winged condition is somewhat different. As a rule the wings of brachypterous specimens of these genera are much shorter than corresponding wings of specimens of *Deltocephalus*. When thus shortened they cover only the basal two or three segments of the abdomen. From the generic standpoint the character of the wing is probably more important than relative size, although in many specific instances in dealing with these species the length alone has apparently been considered. In both of these genera the short winged condition is produced by an entire loss of the apical portion, or abrupt "cutting off" of the elytron in such a way that the venation of only the anterior portion of the wing occurs in brachypterous forms. There seems to be only a slight tendency, if any, for a comparative shortening of the whole elytron when reduced which would cause the cross veins to appear to be pushed forward and cells in the apical portion of the macropterous wings to be shortened.

In *Lonatura* the condition is somewhat intermediate between the other two, but here it is apparently only the reduction of the wing at approximately the apex of the clavus so that more cells are included in the brachypterous wing as compared with *Aconura* and slightly less of the posterior portion is omitted.

As a rule in *Lonatura* no apical cells are found when reduction occurs and frequently all or part of the anteapical cells are missing. In a few cases like *nebulosa* and *megaloopa* formerly

designated as species of *Lonatura* small apical portions are found inside the wing margin. These species however have been placed with their close relatives in the genus *Deltocephalus* and show only a slight remnant of the apical cells.

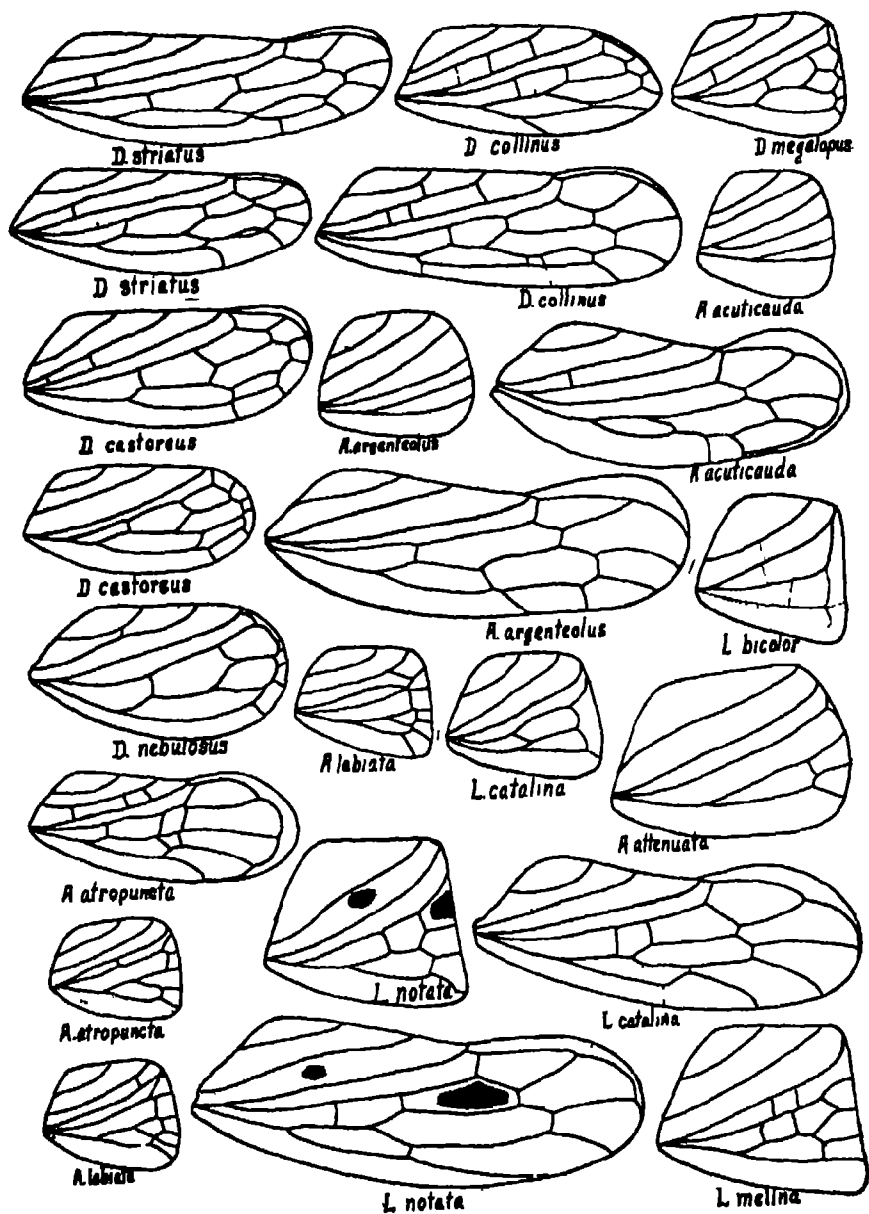
In *Aconura* the wing reduction is even greater and so pronounced in the majority of brachypterous wings that not even a cross vein occurs to separate the elytron into cells. Also the elytron is unusually shortened, the apical margin occurring anterior to the original terminal point of the claval vein. Large numbers of specimens and all the species of *Aconura* have been examined and in no case do apical cells occur in the brachypterous wings. In species like *atropuncta* and *labiata* a few small cells comparable to anteapicals occur at the posterior margin of the wing. But these are so distinct in many respects that they probably should not be placed in the same genus with those designated here as *Aconura*. These brachypterous wings illustrate a somewhat different condition in the wing reduction than do others previously mentioned.

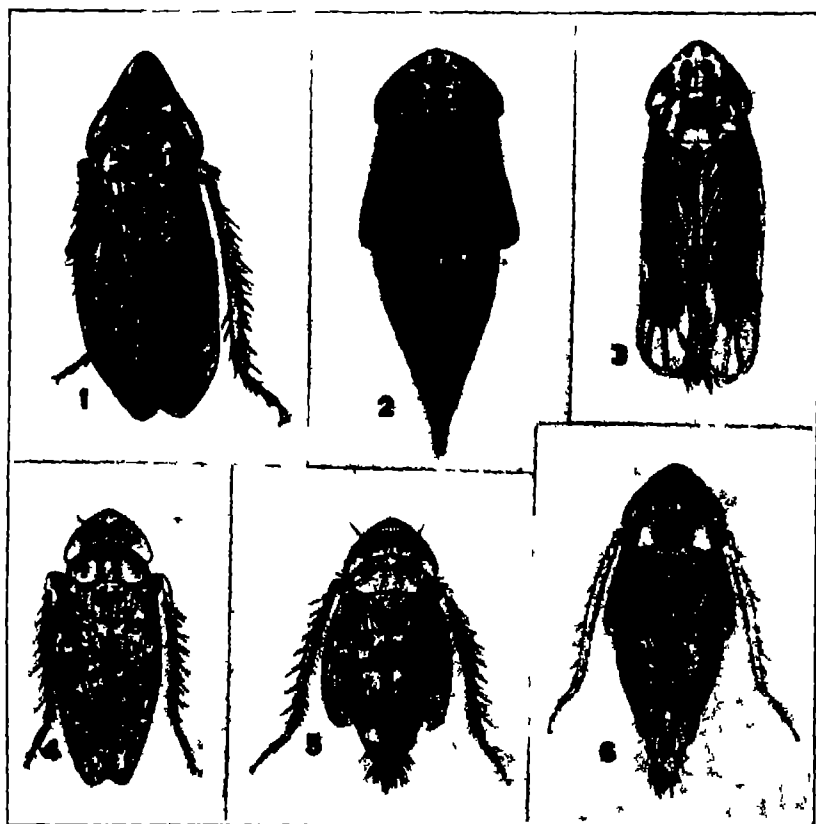
The macropterous form is not known except in a few species of *Aconura*, and certain species of *Lonatura* like *bicolor* are not known to possess long winged forms, although several hundred specimens of a single species have been examined.

In regard to venation proper, the normal and apparently constant condition in the *Deltocephalus* wing is a series of three anteapical cells, with a costal cell beyond the outer anteapical cell. In *Lonatura* there are only two anteapical cells in the long winged forms (*notata*, Plate I) and what is comparable to an outer anteapical extends to the posterior portion of the costal wing margin so that the anteapical and apical cells are combined and the costal cell is apparently wanting. In the genus *Aconura* there seem to be only two anteapicals with the costal cell the same as in *Deltocephalus*. Four apicals are thus formed as in *Deltocephalus* while only three are usually present in *Lonatura*. A few species of *Aconura* as for example *atropuncta* have macropterous wings in which a marginal vein extends from the posterior costal portion to the apex of the clavus. This is comparable to an appendix in other forms but is unique and, combined with other characters, probably represents a distinct genus as previously mentioned.

The wing condition in *Lonatura* and *Aconura* may be only another step in advance of *Deltocephalus* in the process of wing reduction, but as shown in the previous discussion and figures

both the venation and the type of reduction in the elytra indicate generic affinities. This should not be used as an absolute character for determining the generic standing of a species but probably should be emphasized as an important and primary generic character. Investigators who have made a study of the species in these groups have found that the type of genitalia is a very helpful character in attempting to place doubtful species. Many small groups are found whose species are closely related and whose genital structures are very similar. In a few cases these structures are undoubtedly the best to show relationships. Thus the type of wing serves as probably the best although not the final or only criterion for the separation of these genera.





- 1 *Deltocephalus mendosus* Ball (heteromorph)
- 2 *Aconeura acuticauda* Baker (brachypterous form)
- 3 *Lonatura notata* Osborn (macropterous form)
- 4 *Deltocephalus caperatus* Ball (macropterous form)
- 5 *Deltocephalus caperatus* Ball (brachypterous form)
- 6 *Lonatura notata* Osborn (brachypterous form)

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VARIATIONS IN THE FRESHWATER SNAIL, *GONIOBASIS LIVESCENS*

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INTRODUCTION

In the course of some general ecological field work in the Bass Island region of Lake Erie, it was observed that the shells of the snail *Goniobasis livescens* varied considerably in shape and size. It occurred to me that it might be possible to correlate these variations with the degree of exposure to wave action. With this end in view, collections were made in this region during the summer of 1924, while in residence at The Lake Laboratory, Put-in-Bay, Ohio. By way of comparison some *Goniobasis* were collected in the Scioto and Olentangy rivers, near Columbus. The standard used as basis of comparison is the average obesity. My reason for choosing it and the definition of it are given in the section devoted to the description of the method.

On looking over the literature on the ecology of fresh-water mollusks, I have found several instances where variations within a species of mollusks are correlated with environmental factors. This evidence is based partly on actual experiments under control, partly on observations and measurements.

Colton ('08) has shown experimentally for *Lymnaea columella* Say, that the following factors may be the cause of dwarfing large water plants (doubtful results), sediment, cold (indirectly through its effect upon the food supply and directly through its influence upon the physiological processes), improper aeration, volume of water, lack of exercise, and accumulation of excreted matter. He also found that in alternating favorable and unfavorable conditions, as, for instance, cold and warmth, and feeding and starving, the rate

of growth exceeded the rate of those which were always under favorable conditions. This was true even when in the case of alternating temperatures the latter was reduced to the freezing point.

The following is quoted from Colton, *Variations In the Dog Whelk Thais (Purpura Amt) lapillus*. "An examination of a large series of Thais (Purpura), the purple sea snail or dog whelk, from one hundred and six stations seems to indicate that variation in size and shape of shells is the result of the direct effect of environment." Colton found that shells collected from an exposed coast had a relatively wide aperture, (ratio of the height to the width $1.32 \pm .004$) while in those shells collected in sheltered bays with plenty of food the aperture was relatively narrow, (ratio of height to width being $1.70 \pm .009$). Then he goes on to say, "The greater area of the foot (aperture) of those exposed to the surf is a direct reaction to the environment in preventing the animal from being destroyed by the surf. Since there is no overlapping of these characters, it is evident that we are here dealing with the direct effect of the environment." Brot observed in a lake near Geneva, Switzerland, that, "If a snail be long dwarfed and later be put under favorable conditions, the shell is often strangely distorted." Baker ('18) found that *Goniobasis lvescens* varied in obesity in Lower South Bay of Oneida Lake. Some that he found were unusually long and narrow.

Ball, ('22) reports that in some species of fresh-water mussels the obesity seems to be directly proportional to the amount of waterflow. Steuer reports some very interesting variations in several species of plankton that apparently are correlated with environmental factors, namely, temperature, salinity, density of water, depth. Some of these variations occur at different localities, while others appear as seasonal variations at the same locality. Most of these variations consist in an abnormal development or a corresponding reduction of some part of the body, and seem to be a mechanism that enables the organism to float in a medium that varies in density or in salinity at different seasons of the year.

Other instances of the effect of the environment will be mentioned under the discussion of factors that may limit the distribution of mollusca.

Goniobasis lvescens is a fresh-water mollusk. It belongs to the sub-class Streptoneura of the class Gastropoda and to

the family Pleuroceridæ of the order Pectinobrachia. It is the only species of *Goniobasis* found in this region.

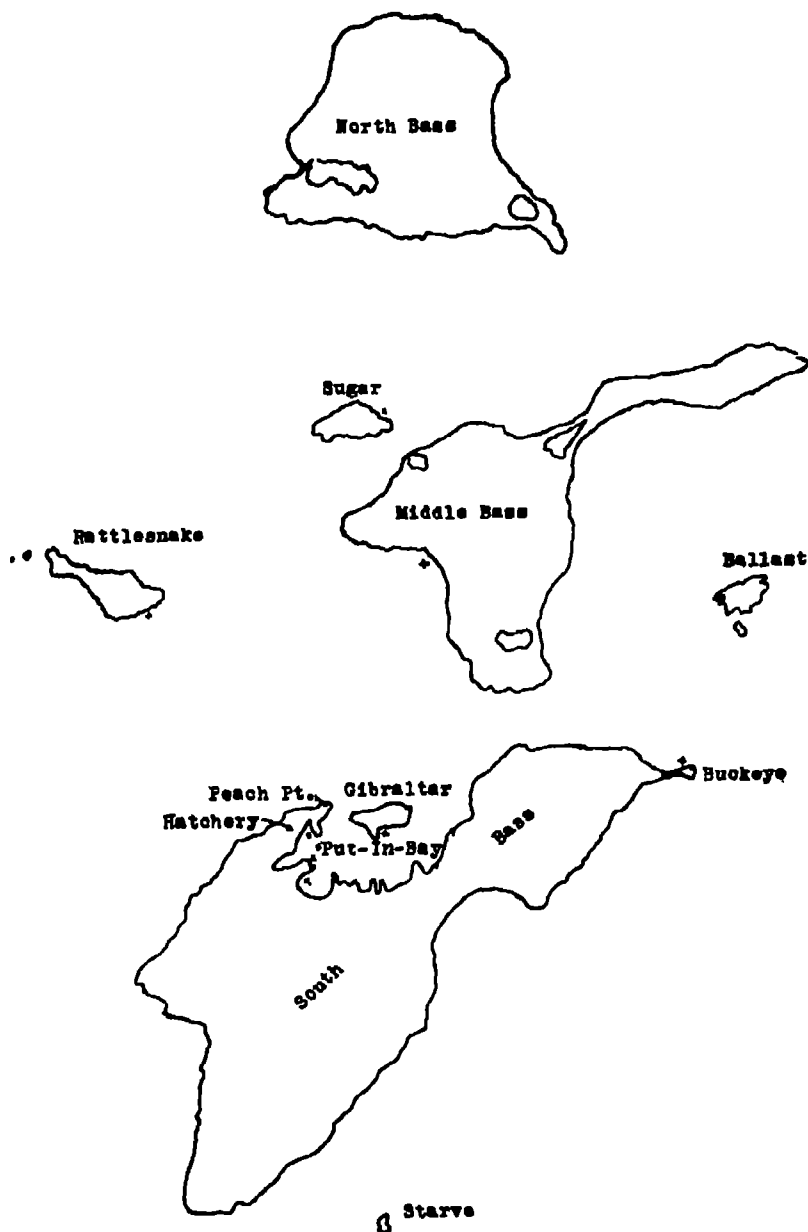
I want to take this opportunity to thank Dr F H Kreeker, under whose direction this work was done, for suggesting the problem and for helpful criticism as the work progressed. The identification of the snail was made by Mr Bryant Walker in connection with some work done by Dr Kreeker. Mr Walker's kindness is greatly appreciated.

METHOD

The first step in the solution of the problem was the selection of a number of stations from which material could be collected. In the selection of stations special attention was paid to the degree of exposure to wave action. The first series of five stations is in the vicinity of the State Fish Hatchery, which is situated on the west shore of Hatchery Bay, a subdivision of Put-in-Bay. The first station, Peach Point, is at the entrance to Hatchery Bay, the second station is an old dock a short distance beyond the entrance to Hatchery Bay and almost in front of the State Fish Hatchery. The third station is along the shore of Hatchery Bay from the U S Fish Hatchery, which adjoins the State Fish Hatchery to Smith's Point at the entrance of Squaw Harbor, another subdivision of Put-in-Bay, the fourth station is the west shore of Squaw Harbor, the fifth station is on the Put-in-Bay side of Gibraltar Island, which lies across the entrance to Put-in-Bay. These five stations represent a definite series with respect to wave action. From Peach Point to Squaw Harbor there is a gradual decrease in the degree of exposure. At Gibraltar the degree of exposure increases again.

The remaining six stations are selected near the following islands and are named after them in the tables: Ballast, Middle Bass, Buckeye, Rattlesnake, Sugar, and Hen. All stations except the one on Hen Island, are indicated on the map of the Put-in-Bay region.

In the collection of snails special care was taken to secure mature individuals. In the young shells the spires are sharp, conical, and the whorls distinctly keeled. While the old shells have obtuse spires and the whorls are not carinated except in some of the very long individuals where the last 2 or 3 whorls may be carinated.



MAP OF THE BASS ISLAND REGION OF LAKE ERIE

Scale 4 cm = 1 mile

Stations are indicated by +

One hundred of the largest specimens from each station were carefully measured to determine the length and the width. The distance from the apex to the lower edge of the lip was taken as the length, while the diameter just above the apex of the aperture was chosen as the width. This width is not quite the same as the greatest diameter, but it is more easily measured and for a comparative study it is just as good. All measurements were made to the tenth of a millimeter with a vernier caliper.

The unit chosen as a standard for comparison is the average obesity. It was chosen because it involves both the length and the width of the shells and is therefore a convenient standard of comparison. The average obesity is defined as the quotient of the average width by the average length. If O = ave obesity, W = average width, and L = average length, we get the equation $O = W/L$.

From this formula it follows that the average obesity varies directly as the average width and inversely as the average length.

The average length is the sum of the lengths of one hundred shells divided by one hundred. Similarly the average width is the sum of the diameters of a hundred individuals divided by one hundred.

Finally the obesity of each shell separately was calculated to get the maximum obesity, the minimum obesity and the difference between these two.

DESCRIPTION OF THE STATIONS

No 1 This station is at the western edge to the entrance of Hatchery Bay. The most characteristic feature of this station is a bar extending into Hatchery Bay in a southeastern direction. The substratum on the northeast side of the bar consists in part of pebbles and small stones and in part of a smooth rock bottom. The shore on this side is subject to almost continual wave action from the open lake. It is exposed to waves coming in from the southwest and also to some coming from the northeast. The substratum on the southeast side of the bay consists of stones varying from a few cubic inches to several hundred cubic inches. This part of the shore is exposed to much less wave action because most of the waves break against the bar or on the shore below the bar. *Goniobasis livescens* were quite common in a few inches of water on the

protected side of the bar, while on the exposed side very few individuals were found and those in deeper water. The water over this area varied in depth from a few inches to a depth of four feet.

No 2 This is a part of an old dock about 50 yards south-east of Station No 1, just beyond the entrance to Hatchery Bay and almost in front of the State Fish Hatchery. The dock is built up of horizontal timbers and then filled up with stones of considerable size. In some places the stones are covered with a few inches of water, while in others they extend above the surface of the water. The water surrounding the dock is about 13 feet deep. This station is less exposed to wave action than Number 1, because much of the effect of the waves is lost when they hit the bar at Peach Point. On both the timbers and the stones *Goniobasis* were found in a few inches of water.

No 3 The edge of Hatchery Bay from the U S Fish Hatchery, which adjoins the State Fish Hatchery, to Smith's Point, at the entrance to Squaw Harbor, another subdivision of Put-in-Bay. The water is uniformly shallow, in most places it is less than 3 feet in depth. The substratum is varied, in part it is composed of a smooth rock bottom, partly of smaller and larger stones, and partly of larger boulders. The shore for some distance consists of a cement wall. Wave action is relatively small, since only waves coming from the northwest could break on this shore and some of these are broken at Peach Point bar, at Gibraltar, and at docks just beyond the entrance to the bay. This makes the part of Put-in-Bay known as Hatchery Bay, a well protected situation. *Goniobasis* are common on the larger stones and boulders, and are plentiful on the cement wall. But everywhere they are in very shallow water, rarely exceeding a foot in depth.

No 4 A subdivision of Put-in-Bay called Squaw Harbor. The water averages around 3 feet in depth and is very turbid. In many places the bottom is covered with mud or silt. Close to the western edge of the shore where the collecting was done, are many large stones barely covered with water. The bank consists in part of large stones piled up artificially and in part of a cement wall. Wave action of any degree is very rare as Gibraltar Island cuts off the waves coming in from the northwest, and South Bass cuts off all waves from the west, south, and practically all that come from the east. *Goniobasis* are

very plentiful on the stones along the bank as well as on the cement wall. I found a number of *Goniobasis* on one stone about 15 feet from the shore and in 3 feet of water.

No 5, Gibraltar Island, situated at the entrance to Put-in-Bay. The north side of the island faces the open lake and all the waves that pass between Middle Bass and Rattlesnake break either at Peach Point or on the north side of Gibraltar. Consequently the north side is exposed to a great deal of wave action. The south side faces Put-in Bay and has very little wave action. The station No 5 is along the protected side of the island. It is not as well protected as Squaw Harbor, because some waves from the northeast may wash this shore. The substratum is composed of stones varying from a few cubic inches to several hundred cubic inches. The water varies in depth from a few inches to about 5 feet. *Goniobasis* are very abundant both on the stones and on the timbers of a small dock, but they always occur in a few inches of water.

No 6, Ballast Island, northeast of the eastern end of South Bass and east of Middle Bass. The island as a whole is exposed to the full force of wave action from the open lake. But on the side facing Middle Bass there is a little cove protected from the northwest by an old dock and from the southeast by a bar. This protection is not sufficient to cut off all wave action. The station is freely exposed to waves from the southeast and also, though to a less extent, to those from the southwest. A look at the map will indicate that Ballast is more exposed than the south side of the bar at Peach Point. But because of this cove, Ballast is less exposed than Buckeye, which will be described next. The substratum is made up of larger stones. *Goniobasis* are abundant on the stones in a few inches of water.

No 7. This station is located on the north side of Buckeye Island. The substratum is mostly a smooth rock bottom over which a few boulders have been strewn. The water is very shallow and gets deeper only very gradually. The island is just as much exposed to wave action as Ballast is, and the station here is more exposed than the one at Ballast, because there is neither bar nor dock to break the force of the waves. *Goniobasis* are rather rare and are found on the larger boulders only.

No 8, Rattlesnake Island, about a mile northwest of Peach Point. The entire shore is well exposed to wave action from

the open lake The station is a pile of rock and timber on the side facing Peach Point This side is least exposed This station is more exposed than Buckeye, but it has also a more favorable substratum A few *Goniobasis* of an unusually small size were found on the larger stones and the timbers in a few inches of water

No 9 This station is on the western side of Middle Bass Island near a point where the shore makes a sharp turn towards the west The station is so situated that the wave action is greatly reduced by this curve in the shore Still the station is exposed freely to the waves from the northwest and from the west Rattlesnake, which is due west of this station, helps to reduce the amount of exposure from the west Hence this station is considerably less exposed than the one at Rattlesnake

The station proper is an old dock built up of timbers and then filled in with stones The end farthest out in the lake was only partly filled, so that the water covered the stones to a depth of from 12 to 20 inches A few *Goniobasis* were found on the sides of the dock, but on the inside on stones as well as on the timbers they were quite plentiful in a few inches of water

No 10, Sugar Island, due west of Middle Bass The station is along the northeastern shore of the island While Sugar Island on the whole is less exposed to wave action than is Rattlesnake, the station proper is more exposed than the one at Rattlesnake It gets the full force of waves from the open lake passing between Middle Bass and North Bass and also waves passing to the west of North Bass It is therefore well exposed and gets the full force of both the east and northeast winds The substratum is partly a smooth rock bottom and partly smaller and larger boulders The water varies in depth from a few inches to about 3 feet *Goniobasis* are rather rare and are found only on the larger stones and boulders and at a depth averaging about 18 inches

No 11, Hen Island, about 10 miles south of South Bass It is out in the open lake and is exposed to the full force of wave action from all directions There are no islands near enough to break the force of the waves as there are at Sugar Island Hen has therefore, a higher degree of exposure than any other station in this series The station proper is a dock built in the shape of a capital L It extends for about 30 feet into the lake and then for about an equal distance it extends parallel with the shore The average depth of the water surrounding

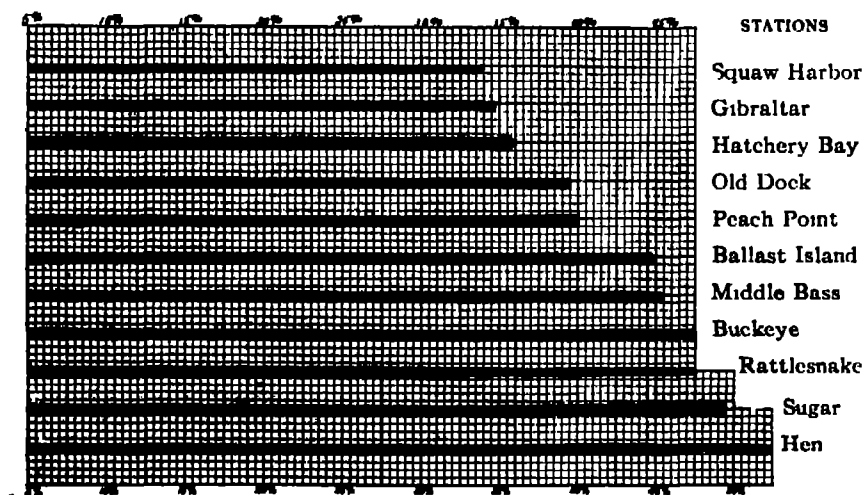
the dock is about 4 feet. A few *Goniobasis* were found on all sides of the dock and also on the larger stones between the dock and the shore. However, at the bend in the dock where the floor and the side of the dock had been partly torn up, and where large stones were submerged in shallow water, *Goniobasis* were quite plentiful. The description of the dock might create the impression that this station is after all fairly well protected. It must be remembered, however, that when the winds come from the right direction the dock and boulders are exposed freely to waves from the open lake. Again snails migrate into less protected areas during fair weather, then when it gets rough they seek a sheltered place.

In the description of the stations three factors have been emphasized, namely, substratum, depth of water, and degree of exposure to wave actions. It is readily apparent that these stations differ principally with respect to exposure to wave action.

RESULTS

Measurements and calculations made as suggested in the paragraphs on method, soon yielded some very definite results. These results are embodied in Tables I-IV. The average obesities are also represented graphically.

GRAPHIC REPRESENTATION OF OBESITIES AT



Percentages of Obesity represented by horizontal lines. One square = 5%
(The first five percent are not shown)

Table I shows the average obesity, mean obesity, minimum obesity, maximum obesity, and the difference between the last two. All are in terms of percent.

The first column of Table I is the most important, since the average obesity is the standard of comparison. It might be well to recall at this point that the stations in Tables I-III are arranged with reference to the degrees of exposure. From Peach Point to Squaw Harbor the degree of exposure is decreasing, while from Gibraltar to Hen Island it is again increasing. Squaw Harbor has the lowest degree of exposure.

TABLE I

Station	Average Obesity	Mean Obesity	Maximum Obesity	Minimum Obesity	Difference
	Percent	Percent	Percent	Percent	Percent
Peach Point	40.00	40.45	49.70	31.20	18.5
Old Dock	39.40	40.00	50.30	29.70	20.6
Hatchery Bay	35.8	36.65	44.5	28.8	15.7
Squaw Harbor	33.6	32.2	43.3	27.1	16.2
Gibraltar	34.1	38.45	48.1	28.8	19.3
Ballast	44.6	46.05	52.4	39.7	12.7
Middle Bass	45.20	44.55	54.7	34.4	20.3
Buckeye	47.4	48.5	55.9	41.1	14.8
Rattlesnake	47.5	49.05	58.2	38.9	19.3
Sugar Island	40.3	48.25	55.6	40.9	14.7
Hen Island	52.44	56.2	67.3	45.1	22.2

On examining the figures of the first column of Table I, it is at once apparent, that (1) a very distinct difference in the average obesity exists, (the total variation amounting to 18.84%, and (2) that these variations in average obesity follow the variations in the degree of exposure to wave action, i. e., from Peach Point to Squaw Harbor the average obesity decreases and from Gibraltar to Hen Island it again increases. In short the average obesity seems to be directly proportional to the degree of exposure.

Column 2 shows the mean obesity and with the exception of Middle Bass and Sugar Island, it follows the same trend as the average obesity.

The maximum obesity varies in case of Sugar Island and Old Dock. The minimum obesity varies in the case of Middle Bass and Rattlesnake.

The greatest difference between the maximum and the minimum occurs at Hen Island and amounts to 22.2%. The least difference occurs at Ballast and amounts to 12.7%.

Table II gives the average lengths, mean lengths, maximum lengths, the minimum length, and the difference between the maximum and the minimum

Column one shows that with a few exceptions the average lengths follow the same trend as did the average obesities, namely, the average length increases from Peach Point to Squaw Harbor, when it reaches the maximum, then at Gibraltar it begins to decrease until a minimum is reached at Rattlesnake. For Sugar and Hen Islands the average length is again slightly greater

TABLE II

Station	Average Length in mm	Mean Length in mm	Minimum Length in mm	Maximum Length in mm	Difference
Peach Point	17.86	18.1	14.5	21.7	7.2
Old Dock	18.12	19.85	15.0	24.9	9.9
Hatchery	19.70	20.4	16.4	26.1	10.0
Squaw Harbor	20.86	21.2	16.4	26.0	9.0
Gibraltar	20.25	21.9	16.8	27.0	10.2
Ballast Island	19.26	20.5	16.0	25.0	9.0
Middle Bass	16.01	16.45	13.5	20.2	6.7
Buckeye Isl	15.6	16.5	12.4	20.6	8.2
Rattlesnake	13.89	15.65	11.3	20.0	8.7
Sugar Island	14.62	16.5	12.4	19.9	7.5
Hen Island	14.87	16.5	12.4	20.6	8.2

The mean lengths follow the same trend as the average lengths and presents the same deviations from the average obesities

The greatest maximum length, 27 mm, is found at Gibraltar and the least, 19.9 mm, at Sugar Island. The greatest minimum length, 16.8 mm, occurs at Gibraltar, and the least, 11.3 mm, at Rattlesnake

The greatest variation in length, 10.2 mm, occurs at Gibraltar, the least, 6.7 mm, at Middle Bass

The specimens from Squaw Harbor and Gibraltar are exceptionally long for *Goniobasis livescens*. In a private letter to Dr. Kreeker, Dr. Bryant Walker stated that the *Goniobasis livescens* he (Dr. Kreeker) sent him, were the longest he had ever seen, with the exception of specimens from Presque Isle, and that these specimens almost warranted description as a special variety

Table III shows the width, mean widths, maximum widths, minimum widths, and the difference between the last two

The average widths differ from the order followed by the average obesity in case of Middle Bass and Rattlesnake. The mean widths vary in the case of Hatchery Bay, Middle Bass, and Rattlesnake. The maximum widths vary in the case of Squaw Harbor, Gibraltar, Middle Bass and Rattlesnake. The minimum width differs in the case of Hatchery Bay, Middle Bass and Rattlesnake.

TABLE III

Station	Average Width in mm	Mean Width in mm	Maximum Width in mm	Minimum Width in mm	Difference
Peach Point	7 16	7 25	8 5	6 0	2 5
Old Dock	7 13	7 25	8 5	6 0	2 5
Hatchery Bay	7 08	7 35	8 4	6 3	2 1
Squaw Harbor	6 95	7 15	8 6	5 7	2 9
Gibraltar	7 01	7 35	8 5	6 2	2 3
Ballast Isl	8 69	9 0	10 5	7 5	3 0
Middle Bass	7 25	7 1	8 7	5 5	3 2
Buckeye	7 40	7 7	9 4	6 0	3 4
Rattlesnake	6 60	6 65	8 3	5 0	3 3
Sugar Island	7 22	7 65	9 0	6 3	2 7
Hen Island	7 80	8 25	10 1	6 4	3 7

Not including column five of Table III all the maxima occur at Ballast and all the minima at Rattlesnake. The shells from the former place were exceptionally large and those from the latter were unusually small.

It could hardly be expected that the average lengths and the average widths would run exactly parallel with the average obesity. What I mean is this, that there may be instances where the average obesity increases even if the average width decreases, or that the average obesity may increase even when the average length increases. This is true because the average obesity depends on both the average length and the average width. But as Tables I and II show, this does not happen very often.

More deviations would be expected in the means of either obesity, length or width, since they represent the average of only two individuals in each case. And in the maxima and minima deviations could be still more frequent in as much as they are measurements of only one individual in each case. With this in mind one can easily see how Squaw Harbor can

have the lowest obesity and yet not have the greatest maximum length Or, that Ballast can have the maximum average width and yet not have the greatest average obesity Or, again that Rattlesnake, with the least average width, still can have the third largest average obesity

The average obesity, since it is dependent upon both the average length and the average width of at least one hundred shells in each case, would seem to be the most reliable criterion as far as the results embodied in Tables I to III are concerned

Table IV is a record of the results obtained on the *Goniobasis livescens* in the Olentangy and the Scioto Rivers near Columbus It seems to show that there is some difference in obesity in the rivers and that the obesity is correlated with the rate of flow However, the amount of data is too limited to draw any conclusion

TABLE IV

Station	OLENTANGY			SCIOTO		
	Av L	Av W	Avc O	Av L	Av W	Av O
Rapids	15 53	6 37	41 01	17 73	7 11	40 10
Pool	18 8	7 12	37 86	18 29	7 22	39 47

The volume of water in the rapids in the Olentangy was much greater than that in the rapids on the Scioto This is probably the reason why the difference in obesity in the Olentangy is greater than in the Scioto Another reason for the small difference in obesities at the Scioto is that, in my judgment, the snails in the pools might at times be subject to draught

It might be well to point out here that wave action and rate of water-flow expressed in volumes are not quite identical Wave action is more nearly identical with the rate of flow and the volume of flow combined The volume of flow might be relatively large, but if its flowing is slowly and steadily, it would jar the snails less than would a much smaller volume if flowing at a greater rate

DISCUSSION

On examining Tables I-III it becomes at once apparent that the degree of obesity is very definitely correlated with the degree of exposure to wave action This is especially well illustrated by the first six stations, namely, Peach Point, Old

Dock, Hatchery Bay, Squaw Harbor, Gibraltar and Ballast. It is again quite striking when any two of the remaining five stations are compared or when any one of them is compared with any one of the first six, but especially when compared with Gibraltar and Squaw Harbor.

The differences in obesity are produced in two ways (1) in some shells the top is worn off so that several whorls are missing, (2) many shells are very bulbous, which makes the ratio of width to length high.

Before attempting to explain the relation of obesity to exposure some other factors that might limit the distribution and development of *Goniobasis lvescens*, or any other gill-breathing mollusk, will be considered. These are temperature, oxygen supply, CO_2 in the water, nature of substratum, depth of water, and exposure to wave action.

TABLE V

Station	Squaw Harbor	Gibraltar	Peach Point
Average Temperature	75.5° C	73° C	74° C

Temperature cannot be of much direct influence and cannot account for the differences in size and shape of *Goniobasis lvescens*. All these stations are frozen over during the winter months and hence the snails must in all cases be able to endure a temperature not above 4° C. The average temperature is probably slightly lower in the more exposed area, because of the water being mixed with water from the deeper and cooler portions of the lake. While the average temperature for Squaw Harbor is, perhaps, more favorable, it is equally true that Squaw Harbor is subject to great diurnal changes in temperature as well as in alkalinity. Temperature readings are here given for the north side of the bar at Peach Point, for Squaw Harbor, and for Gibraltar. These readings were made during July, 1923.

Table V shows the average temperature for the month is very nearly the same, for all the three stations considered. Then in comparing Table I and V, we note that while the average temperature at Peach Point is more favorable than that at Gibraltar, the average obesity at Peach Point is 59% greater than that at Gibraltar. If temperature were a determining factor, we would expect that the obesity at Gibraltar would be greater than at Peach Point.

Table VI brings out the great daily variations in temperature in a protected place, like Squaw Harbor, and the relatively small variations in a more exposed place, like Peach Point. The conditions at Peach Point and at Squaw Harbor may be taken as representative of all exposed and protected stations respectively—provided the depth of the water is the same.

If it is true that a constant temperature is more favorable for growth and normal development than one that varies considerably, it would appear, as far as temperature is concerned, that Peach Point is the more favorable environment of the two stations, for here the variation is only 4° C, while it is 16° C at Squaw Harbor. The difference in the amount of variation is easily explained, the water at Peach Point, though shallow, is continually mixed with water from the cool portions of the lake, while the water at Squaw Harbor, also shallow, is ordinarily not mixed with lake water.

TABLE VI

Station	Time of Day	Temperature	Ph
Squaw Harbor	9 A M	70° C	8
	11 A M	78° C	8
	4 P M	86° C	9
Peach Point	10 A M	72° C	8
	11 A M	73° C	8
	4 P M	70° C	8

Note These readings were taken July 9, 1923

Temperature has undoubtedly an effect upon the rate of growth. Howard has shown that the growth in fresh-water mussels occurs during the warm summer months. This is likely also true for *Goniobasis livescens*, but the variations in temperature as shown above are hardly sufficient to produce any change in the rate of development. Much less could it be the cause of the remarkable differences in shape and consequently the obesity.

Temperature could also have an indirect effect through the food supply. That it is not a limiting factor in this respect is evidenced (1) by the growth of filamentous algae on the stones where snails were collected, (2) in most instances the shells were heavily covered with algae, and (3) that if they feed on plankton at all—which according to Baker is doubtful—my plankton studies in (23) show that diatoms, desmids, and

several unicellular algae are quite abundant even in places that are exposed to the full force of the waves from the open lake, as for instance, the western shore of South Bass

The oxygen supply cannot be a limiting factor, because most stations are in shallow water, and where this is not the case, as at Old Dock, the snails live near the surface of the water. The wind stirs the water sufficiently to keep it well supplied with oxygen

Carbon dioxide may affect Mollusks in two ways. If present in large quantities it becomes toxic and thus kills them. Again, if mollusks live in soft water or in water containing only small amounts of CaCO_3 and CO_2 is present in considerable quantities, it might combine with CaCO_3 of the prismatic layer, (when the periostrum is ruptured), and the nacre to form the soluble $\text{Ca}(\text{HCO}_3)_2$, (Cooker, Shira, Clark, and Howard), (Hegner). CaCO_3 is abundant in all these stations

My determinations of the concentrations of free CO_2 and the hydrogen ion in this region of Lake Erie show that the water contains at the most very minute traces of CO_2 . This of course would be expected, for the water is shallow and almost continually stirred by slight winds, making it easier for the CO_2 to escape. Again as the temperature increases, the capacity of the water to hold CO_2 is decreased. The hydrogen-ion concentration in any of these places is not above $\text{PH}=8$. This means that the water is very decidedly alkaline. Before CO_2 in solution could attack the mineral components of the shell it must neutralize the excess OH-ion of the water. But CO_2 dioxide is not chemically active until it has combined with water to form H_2CO_3 , which in turn is ionized to form $\text{H}^+ + \text{HCO}_3^-$, and because if it had done this, the H-ion would first combine with OH-ion to neutralize the water, and again because we find the water decidedly alkaline, it follows that an excess of dissolved CO_2 does not exist

The nature of the substratum is also of great importance in the distribution of mollusks. Adamstone ('21) has shown it to be of importance in the distribution of Mollusca in Lake Nipigon. Cooker, Shira, Clark and Howard have called attention to the importance of the character of the substratum in the case of fresh-water mussels. Howard again in the artificial rearing of fresh-water mussels has ascribed great significance to the nature of the bottom. Kreckler ('24) has shown that the substratum is an important factor in the distribution of

Goniobasis livescens Baker reports *Goniobasis livescens* from 15 stations in Oneida Lake, but in every instant he states that they are found on boulders

Undoubtedly the substratum does play an important part in the distribution of different species of Mollusca, including *Goniobasis livescens* But in my opinion it does not account for the great variations in obesity as shown in Table I, column one Take, for instance, the substrata of Old Dock, Middle Bass, and Hen Island, which are as nearly alike as any three substrata could be Yet the average obesity at Old Dock is 39.3%, that at Middle Bass is 45.2%, and that at Hen Island is 42.44% Again the substratum at Sugar Island, on account of the many large boulders, is really more favorable than the substratum at Buckeye Still the average obesity at Sugar is 49.3%, while that at Buckeye is 47.4% Apparently the substratum does not account for the differences in obesity

The depth of the water is another factor that may limit the distribution of Mollusca and they are accordingly divided into deep water species and shore species No variations in my snails can be ascribed to a difference in depth, since all collections were made in approximately the same depth of water The water at all the stations except Old Dock does not vary more than two feet in depth, and even here the snails were near the surface

Food is not only an important factor, but it may become a limiting factor for any form of life, especially animal life Yet it is not probable that the difference in obesity could be explained on a basis of food It is certain, as Colton has shown, that a shortage of food may produce dwarfing, but as far as I can tell there exists no shortage of either organic or inorganic food It has already been emphasized in connection with temperature that organic food is abundant And under the discussion of CO_2 it has been shown that there is no shortage of CaCO_3 Yet if there were a shortage of CaCO_3 , the only difference that would be likely to be produced would be a reduction in the thickness of the prismatic and the mother-of-pearl layers, and would not necessarily affect the shape nor the length of the shell Even a total absence of these layers would not produce a great difference in the ratio of the width divided by the length Incidentally it happens that the obesity is least in Squaw Harbor where the alkalinity is greatest

Wave action Adamstone ('21) concludes that aside from the food supply the degree of exposure to wave action is the principal factor that limits the distribution of mollusca in Lake Nipigon Kreckler ('24) has shown that the distribution of *Goniobasis livescens* is definitely correlated with wave action I have had ample opportunity to confirm Kreckler's conclusions Baker states that in Lake Oneida *Goniobasis livescens* are more abundant on a bouldery shore than on a bouldery point Perhaps this could be explained on a basis of exposure

My results as recorded in Table I, show as far as they go conclusively, (1) that variations in obesity are correlated to the exposure to wave action, and (2) that the obesities are directly proportional to the degree of exposure to wave action, i e, the obesity is increased whenever the degree of exposure is increased

This is in line with the results obtained by Ball ('22) in the case of certain species of fresh-water mussels Ball found that in certain species the obesity increased, with an increase in the volume of water flow It is perhaps well to note that wave action and volume of water-flow, as used by Ball, are comparable, but are by no means identical Jarring and vibrations play a much greater part in wave action than it necessarily would in a stream This would probably make no difference in the case of mud-burying mussels, but it makes a big difference for *Goniobasis livescens* My results also agree with those obtained by Colton ('22) in the case of the Dog Whelk, as indicated in the introduction

If obesity is a function of wave action, how is this relationship brought about? It has already been indicated that the great differences in obesities are produced in two ways, (1) in some shells in the more exposed situations, the apex is worn off considerably, and (2) the shells in the exposed situations are very bulbous at the base and then taper sharply while in the protected situations the base is no more bulbous than any other part of the shell and they taper off very gradually The wearing off of the apex accounts only for a small amount of the increase in obesity, for even some specimens from the most protected stations have the apex worn off It is true, as Table II shows, that there is a decrease in the average lengths in the more exposed stations But this decrease in lengths is due largely to the fact that in specimens from the exposed places the whorls above the first one are very much narrower than

corresponding whorls of the specimens from the protected stations. Again in referring to Table III, we note that the increase in the ratio of the width to the length is due not alone to a decrease in length, but also to a decided increase in the width.

Number (1) can easily be accounted for by the mechanical action of the waves—the wearing off of the apex is analogous to the erosion of rock strata by streams. Number (2) is either a germinal difference or it is the result of the direct effect of the environment—in this case thought to be the wave action.

The assumption that these variations in shape are hereditary and that the whole thing is a matter of natural selection is open to the following objection. If it is a matter of a survival of the fittest—best fitted to the environment—why is there so little overlapping in the protected situations?

Why are practically all the shells at Squaw Harbor and Gibraltar for example elongate, while all the shells at Middle Bass or Sugar Island are of the bulbous or obese type? If conditions at Gibraltar or Squaw Harbor are favorable for the snails with a long slender shell, why would not that same environment be favorable for snails with a short bulbous shell and a larger foot? (The ratio of the length of the aperture to the width of aperture in Squaw Harbor is 167 0, while at Sugar Island the same ratio is 150 2).

Again the assumption that the differences are environmental variations is open to criticism for lack of experimental evidence to that effect. It is true Colton has shown that various environmental factors—see introduction—may cause dwarfing, but it has not been shown for *Goniobasis livescens*. The final answer then will have to wait until breeding experiments can be carried out to show whether these variations are hereditary or not.

Supposing that these variations are not hereditary and that they are the result of wave actions, how could this relationship be explained? The effect of wave action is perhaps of two kinds, (1) it may be the cause of dwarfing, i. e., a snail develops so slowly that it might never develop the full number of whorls. (It is pointed out by Colton that shells of the same size, but of different age have the same number of whorls, (2) it may change the direction of growth, shells instead of becoming long and slender become short and obese.

Just how wave-action produces this effect is not known, neither is it known how other environmental factors produce temporary variations. But it is entirely possible that this jarring coming at some critical period in the development changes the direction of growth.

SUMMARY

1 The average obesity is directly proportional to the degree of exposure to wave action

2 The differences in obesity are due to a wearing off of the apex and to a difference in the shape of the shell. The latter accounting for the main part of the difference

3 The more obese shells have a larger aperture and hence a larger foot

4 What is true as to the relation between obesity and exposure to wave action in the lake is probably also true for the Scioto and Olentangy rivers near Columbus

5 It cannot at present be decided whether these differences in shape are due to heredity or whether they are the result of the direct effect of the environment

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FOOD PLANT AND HABITAT NOTES ON SOME NORTH AMERICAN SPECIES OF PHLEPSIUS

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A systematic treatment of the North American species of *Phlepsius* by Prof. Osborn and Dr. Lathrop appeared rather recently*. This is an excellent paper for the separation and identification of our North American species. Probably in an attempt to abbreviate the paper, food plant notes and ecologic data were omitted. The present treatment is undertaken in order to give some notes on personal observations in the field and to show some of the interesting diversities in habitats of the members of this genus.

Probably one of the most interesting groups of the genus and one which is apparently quite distinct in coloration and food habits from the other species, contains the so-called "banded" species of *Phlepsius*. This group includes those forms which are definitely marked by cross bands of darker brown coloration giving the insects the general appearance of markings of alternating light and dark brownish transverse bands. In all cases where food plants have been definitely determined for these species they have been found feeding upon some species of pine. *Phlepsius nigrinus* and *Ph. franconianus* occur together, frequently being found on the same tree or limb. Mr. Knull has collected both species from White Pine, *Pinus strobus*, in the Allegheny Mountains of Pennsylvania. The writer has also secured them from this food plant in Pennsylvania and in Ohio has taken them abundantly on *Pinus rigida* and *P. virginiana*. In Ohio *Ph. tullahomae* has frequently been taken with them also. In a previous paper† the writer pointed out that this species was not a tree inhabitant and that it occurred on *Andropogon*. This statement was made in error, as more recent investigation has shown that minute seedlings of *Pinus virginiana* and *rigida* were growing in what seemed to be a pure *Andropogon virginicus* association. The seedlings were only a few inches in height and completely hidden by the clumps of *Andropogon*. Although most abundant on these

*Ann. Ent. Soc. Amer. Vol. 16, p. 310, 1923.

†Conn. Geol. and Nat. Hist. Surv. Bull. 34, p. 130, 1923.

small succulent pines, they also occur and have recently been taken in nymphal and adult stages from older trees

The same mistake was made at first regarding the food plant of *Ph palustris*. Seemingly it was swept from a heavy sedge, *Juncus megacephalus*, but close observation revealed in that case also small seedlings of *Pinus palustris* and it was afterwards taken from larger pines where no sedges occurred. This species is by far the largest and most robust of the banded group. *Ph slossoni* and *Ph lippulus* are both southern species and live on pine. Food plant records to date, however, show them to be confined to different species of pine. *Ph slossoni* has been taken only from *Pinus caribea* and *Ph lippulus* only from *Pinus palustris*. Further observations may show a wider range of food plants for each of these species. *Ph strobi* receives its name from the white pine on which it lives. This species has long been confused with a species of *Eutettix*, feeding on *Chenopodium*, which error has recently been pointed out by Prof Osborn. *Ph granticus* is also reported by Lowry as occurring on pine in New Hampshire.

A number of species of the genus also occur on the floor of the pine woods. In Florida several species live in this habitat, some of which are found farther north. *Ph floridanus* and *Ph attractus* occur on the fine short grasses of the pine forest floor in well drained areas. *Ph nudus* and *Ph tubus* occur on similar small grasses in open pine woodland. *Ph pulchripennis* is found for the most part under pine woodland conditions, but on herbaceous growth and where the soil is apparently more moist. In addition it occurs on grasses bordering the everglade areas and was taken from grasses in open portions of the everglade hammocks. In these three habitats the conditions under which it occurs are similar. *Ph distinctus*, another grass species of the open pine woods, was found only where the growth was very luxuriant and the woods sufficiently open to favor a heavy growth of the herbaceous layer and to present the appearance of a savannah. The food plant could not be determined.

Present records would indicate that very few species are known to live on trees or shrubs other than pine. *Ph tinctorius*, probably an imported species, is known only from the New York, Newark, N. J., area, where it occurs on *Aralia spinosa*. *Ph marmor*, known at present only from Manitoba, is reported from *Juniperus horizontalis*.

The great majority of the species are grass feeding and occur under varying conditions. In addition to those mentioned as occurring on the herbaceous growth of the pine woodland floor, several are abundant in the swamp and marsh. Two species especially are common in the Florida everglades. *Ph planus* is abundant on *Panicum hemitomum*, the maiden cane, and *Ph cottoni* occurs in the *cladium effusum*, sawgrass, association. *Ph latifrons* also occurs in the everglade region on the moist prairies, but is found in more northern states as a meadow species.

Several different conditions are found in the fresh water swamps and marshes of the northern states. From field observations probably no species of *Phlepsius* could be designated as a true swamp form. *Ph solidaginus* would approach this condition quite closely, however, as it is common on the tall grasses of the fresh water marsh in a mixed association of *Carex-Phragmites*. *Ph ramosus* has been taken from a similar habitat, but no specific data was obtained regarding the food plant. *Ph fuscipennis* and *Ph collitus* have been found very abundantly on short growths of *Juncus*, *Eleocharis obtusa* and *Scleria verticellata* at the margins of fresh water lagoons, where the small waves of the lagoon keep the sandy soil very moist and produce a very humid habitat. *Ph nebulosus* has also been taken abundantly from the same plants, but where they were growing under different conditions. In this case the water had receded in the old lagoon basin so that a somewhat drier condition prevailed and the plants had formed a mat or turf.

At least two species are definitely associated with the bog habitat. Prof. Osborn has reported collecting *Ph maculellus* on fine grasses in the bog association. *Ph ramosus* also occurs in boggy areas and has been taken from clumps of grass growing in a mixed *Sphagnum-Tamarack* habitat.

A few species undoubtedly live most abundantly under heath conditions. *Ph fulvidorsum*, although occurring in woodland areas, is found in greater abundance on one of the herbaceous plants in the heath association. It occurs in an association where *Smilax* sp., *Vagneria* and associated plants are found. *Ph cumulatus* is another and more typical heath species, but is found under entirely different conditions from the preceding. It has been collected abundantly from mats of a pure association of *Arctostaphylos* (bearberry) which forms a portion of the herbaceous ground layer of plants in the northern conifer forests.

The character of the meadow may vary to a great degree. It may be a high, well drained area or a low moist meadow and as a consequence the type of plant and the humidity factor may vary decidedly. For this reason a larger number of species might be placed as meadow inhabitants. Several species are common in different types of meadows. In the northern states *irroratus*, *truncatus*, *collitus*, *decorus* and *tennessa* are found abundantly. The first three of these are very common. In the extremely northern states and Canada *Ph. apertus* is a common meadow species. *Ph. superbus* and *Ph. excultus* are abundant meadow species in certain localities, especially in the southern states.

Large areas of upland pasture and grazing land are covered with *Andropogon virginicus* as the principal species of grass. In this association *Ph. carolinus* and *Ph. cinereus* are found rather abundantly. *Ph. collinus* occurs in the same areas, but probably lives upon the small patches of *Aristida* which are constantly being invaded by the *Andropogon*. In some places it is also found on the washed areas where the *Aristida* is usually the pioneer plant to grow upon these denuded spots. *Ph. altus*, superficially resembling the former species, occurs on the short grasses of the western plains.

Open woodland areas of the deciduous forest, especially in mixed mesophytic forests where the humidity is rather high and there is a rich growth of herbaceous plants, furnish the proper habitats for several species. Of these might be mentioned *Ph. particolor*, which has been taken only in a very restricted habitat of this type, where short grasses together with *Luzula campestris*, *Sanicula canadensis*, *Viola blanda* and similar plants occur in a mixed hemlock-beech woodland. *Ph. incisus* occurs in the same habitat, but is found living under more varied woodland conditions. *Ph. decorus* and *Ph. fulvidorsum* may also occur under woodland conditions, but the relative degree of humidity may be much lower in the case of these latter species. *Ph. majestus*, also a woodland species, occurs on tall grasses growing in moist areas in rather dense shade where only a few herbaceous plants are found.

This data collected while observing field conditions of these insects in the Eastern U. S., shows a great diversity in food plants and types of habitats. If similar data could be brought together for the western species as well, it would probably show even a greater diversity of conditions, especially in the case of the mountain species and those of the arid southwest.

THE LIMESTONE CAVES AND CAVERNS OF OHIO

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INTRODUCTION AND ACKNOWLEDGMENTS

The limestone caves and caverns of Ohio, with two or three exceptions, have not previously been described. The presence of such natural phenomena at various places in the State has been known, but aside from the locations of the larger ones no definite information, especially under one head, has been available. While no Ohio cave known is as much as a half mile in length, nevertheless many of them present features worthy of description, and all have at least local interest.

This paper was prepared under the direction of Dr J A Bownocker, who outlined the problem, offered valuable advice during the progress of the field work, and aided greatly in the preparation of the manuscript in its final form. The writer takes this means of expressing his sincere thanks and appreciation for the assistance. The Geological Survey of Ohio provided funds for field expenses and for the tracing of maps. I wish to thank Dr J E Carman for the stratigraphy of the Monroe, Dr August F Foerste for information on the Niagara of the Rocky Fork region in Highland County, and Dr William J McCaughey for advice on the deposits and help in mapping Zane's Cavern. Assistance which was necessary in surveying all the caves was given by Messrs Irvin C Colman, Paul E Fitzgerald, Wendall Camp, and P J Harris, friends of the

writer The rough field maps were traced, section-lined, and lettered by Prof W D Turnbull, and the fine quality of his work is self-evident



LOCATION OF THE CAVES AND THEIR GEOLOGICAL HORIZON

The location of the caves is, in a broad way, in the western half of the State from Put-in-Bay in Lake Erie on the north, to Highland County on the south (Map 1) Stratigraphically, they occur from the base of the Niagara (Silurian) to the top of the Delaware (Devonian) The Ordovician limestones of the State are too thin bedded and argillaceous to permit the formation of caves

SECTION SHOWING THE GEOLOGICAL HORIZON OF OHIO CAVES AND CAVERNS

Devonian System	{	Delaware limestone	Lawrence Cave
		Columbus limestone	{ Ohio Caverns Zane's Cavern Good's Cave
Silurian System	{	Monroe Series	{ Put-in-Bay Caves Crystal Rock Caves Buckskin Caves
		Bass Island formation	
	{	Niagara Series	{ Underground River Cave Miami River Cave Painter Creek Cave Rocky Fork Caves

The limestone caves of the State, with the exception of those of Rocky Fork, are located where there have been at least two periods of continental glaciation, and thus the relief is not great. Such a condition is not favorable for the formation of vast caverns with many levels, such as those in Kentucky and Indiana. Perhaps the advance of the great ice sheets removed some existing caves entirely and obliterated evidence of others.¹ Doubtless additional caves will be discovered in Ohio from time to time, due to the collapse of roofs and openings becoming evident which are now filled with glacial drift.

It is probable that most, if not all, of the fissure type of caves in the State antedate, at least in their beginning,² the first advance of the glaciers into the area. The pre-glacial origin of the Rocky Fork Caves is more fully discussed under that heading. The time necessary for solution of the limestone, and that for the formation of the deposits, seems longer than post-glacial time.

TYPES OF CAVES

The limestone caves of Ohio are of two types. Most of them belong to the fissure variety, produced by solution of the rock usually along joint planes. Their origin is discussed later. The second variety is that in which the floor and roof seem at one time to have been in contact, and is best typified by those on Put-in-Bay. No satisfactory name has been proposed for this, and for convenience, it will be referred to in this paper as the "Put-in-Bay" type.

¹Hubbard, Geo. D., Geol. Surv. Ohio 4th Ser. Bull. No. 14, 1911, pp. 61-65.

²Ibid., p. 63, also Hills, T. M., 'Reames Cave, Ohio Jour. Science, Vol. XVI No. 6, pp. 209-215.

The caves on Put-in-Bay, those in Crystal Rock Park, and Good's Cave belong to this type. Others described are of the fissure or joint-plane type. Good's Cave, while presenting an aspect somewhat similar to those of Put-in-Bay, seems to have had a different origin, which is given under its description. The origin of the Put-in-Bay and Crystal Rock Caves will be taken up after the description of the former.

FORMATION OF CAVES AND THEIR DEPOSITS

The fissure or joint-plane type of caves has been formed by solution during a long period. Atmospheric water falling as rain¹ unites with the carbon dioxide (CO_2) of the air and forms weak carbonic acid,



This acidulated water in contact with limestone forms calcium bicarbonate, $\text{CaH}_2(\text{CO}_3)_2$,



In this manner the rock is dissolved and carried away by seeping and flowing waters. The action is usually hastened by humic acid which has been taken up by the water in passing through decaying vegetable matter before reaching the limestone. The crevice through which the water so charged seeps is thus gradually enlarged until a cave is formed. When a stream flows through the opening, action is much more rapid, due to erosion. This, while important in the formation of some of the larger caverns of the country, does not seem to have been very influential in the Ohio caves. In many of the caves of this State all action toward further enlargement has ceased, in some places because of drainage changes by the great ice sheets, and in some from other causes. These caves are said to be "dead," and this feature is mentioned in the description of several of them.

Many limestone caverns are partially filled with secondary deposits called travertine in this paper. In places these are in sheet-like deposits, and elsewhere in the form of stalactites and stalagmites. Their formation is the reverse of that for the solution of primary limestone, the reversion taking place when the water, carrying calcium carbonate in solution, which

¹Blatchley, W. S. "Indiana Caves and Their Fauna." Twenty first Annual Report, Dept. of Geol. and Nat. Resources of Indiana, 1896, pp. 121-123.

seeps into the passages, evaporates and deposits the contained mineral matter¹ Where the water flows over the walls, the deposits are sheet-like in character, but where it drips from the roof a stalactite, which resembles an icicle, is the form taken When the water dripping from the roof is not entirely evaporated before it falls to the floor, a mass is built up below the stalactite, which is broader and called a stalagmite With continued action of this sort, the stalactite grows slowly downward, and if conditions are such that a stalagmite is formed underneath, the two may finally coalesce, forming a column or "stalactostalagmite"² The mineral-laden waters then flow over the column, slowly increasing its size, and these deposits are analogous to the sheet deposits found on the walls

The color of these deposits varies from almost transparent and crystal clear material to muddy brown, the latter caused by foreign particles carried by the water in suspension Beautiful tints caused by iron oxide are often found, varying from faint pink, through salmon and red, to dark brown, according to the amount of iron present Local variations of coloring matter are often very striking³

When deposition in a cavern has ceased, the travertine assumes a dry and ossified aspect, and if the action has ceased for a long time the deposits may look very much like badly weathered bone The deposits of most of the Rocky Fork Caves are of this character

The argillaceous matter in the limestone of these caves, being insoluble, is left behind as residual clay This may cover the floors and walls to depths of six inches or even more The caves in the Cedarville dolomite of the Niagara series (particularly those of Rocky Fork and the Miami River) show this character

METHODS OF MAPPING

While the mapping of each cave presented a more or less particular problem, the procedure was similar with each, with certain minor exceptions A plane table, 15 inches square, with a light tripod was used For orienting, a small compass

¹Deposits from Zane's Cavern were studied in thin section and in powder with the petrographic microscope, and the material was found to have the properties of calcite rather than those of aragonite, the biaxial form of CaCO_3

²Blatchley, W S, "Indiana Caves," Twenty first Annual Report, Dept of Geol & Nat Resources of Indiana, 1896, p 123

³Hills, T M, "Reames Cave," Ohio Jour Science, Vol XVI, No 6, 1916, pp 209-215

sunk in one corner of the table was found to be accurate enough for the purpose but this was checked occasionally with a larger instrument of proven reliability. The magnetic declination in the areas mapped varied from one-fourth to three-fourths of a degree west. A scale of 20 or 40 feet to the inch was the one most employed for the original maps, although variations of these, as can be seen from certain of the maps, were sometimes found to be necessary or advisable. A small peep-sight alidade was employed, as the poor light and the small spaces precluded a larger plane-table and a telescopic alidade. An ordinary tape was used and measurements were usually plotted to the nearest one-half foot, as closer work would not be evident on the maps.

The major points of the map were fixed by radiation or traverse, triangulation sometimes being used as a check. After fixing the major points the walls and passages were sketched with considerable care. An assistant carried a light, usually a flashlight of the common focusing type, although sometimes a candle was used to take bearings on. The work at the plane-table and the sketching was done by the author, with the exception of one or two of the caves. In some of the larger caverns which were lighted by electricity, the work was not particularly difficult, but in most of the caves which were not so lighted, the mapping proceeded more or less slowly. Where the roof was very low, the top of the plane-table was detached, and in some of the very lowest passages, traversing proceeded very slowly because the drawing board had to be pushed ahead of the instrument man, bearings kept, and one end of the tape handled. When it is remembered that where passages were this low, they were frequently covered with mud, and water dripped from the roof, the difficulties in producing an accurate map may be appreciated. Where a cavern had two entrances, or other means of checking were present, this was done, and proved that the maps were almost always as accurate as could be made with the instruments at hand.

The maps in the field were drawn in pencil and later inked. The draftsman traced them, adding the section lining, lettering, borders and so on. Where cross sections are shown, they have been made in the field, or from notes that were later plotted in the office.

On account of the relatively small size and the comparative obscurity of most of the caves in Ohio, few amazing stories as to

size and extent are current about them, as has been the case with some of the more famous caverns of the country¹ However, figures given locally as to size and extent of even the smaller caves may be very greatly exaggerated, some shrinking from miles to hundreds of feet on measurement The veracity of the writer has upon occasion been seriously questioned when the length of certain caves has been given as only a few hundred feet instead of the reported mile or two which the average layman has thought it to be Due account must be taken of the great apparent increase in distances underground, when the only light may be a small flashlight or a feeble candle and the progress is made lying flat, slowly pulling oneself through the mud and slime with which the floors of some of the caves are covered The pool in Wet Cave in the Rocky Fork Group is commonly supposed to be "bottomless," but a strong focusing flashlight reveals the bottom, which certainly is not more than 20 feet below the surface

PUT-IN-BAY CAVES

South Bass Island is one of the larger islands in Lake Erie which is within the boundaries of the State of Ohio Together with Middle Bass Island and North Bass Island it makes up Put-in-Bay Township of Ottawa County The island is four miles from the Catawba Island portion of Danbury Peninsula, the nearest point on the mainland The entire island is incorporated as the village of Put-in-Bay, and this name is used interchangeably with that of South Bass Island It is three and one-half miles long and a mile and a half wide at the maximum, the area being a little more than two square miles The trend of the island is in a north-east and south-west direction The surface is very slightly rolling, the most noticeable topographic feature being the many sink holes, some of which are more than two hundred yards across, but which are rather shallow

The bedrock of most of the island is the Put-in-Bay dolomite, a member of the Bass Island formation of the Monroe series It is thus Silurian in age The member underlying the Put-in-Bay outcrops about 20 feet above water level along the southwest side of the island This is the same member as that which contains the gypsum beds of the mainland It should be the time equivalent of the Tymochtee although it is more shaly than typical Tymochtee²

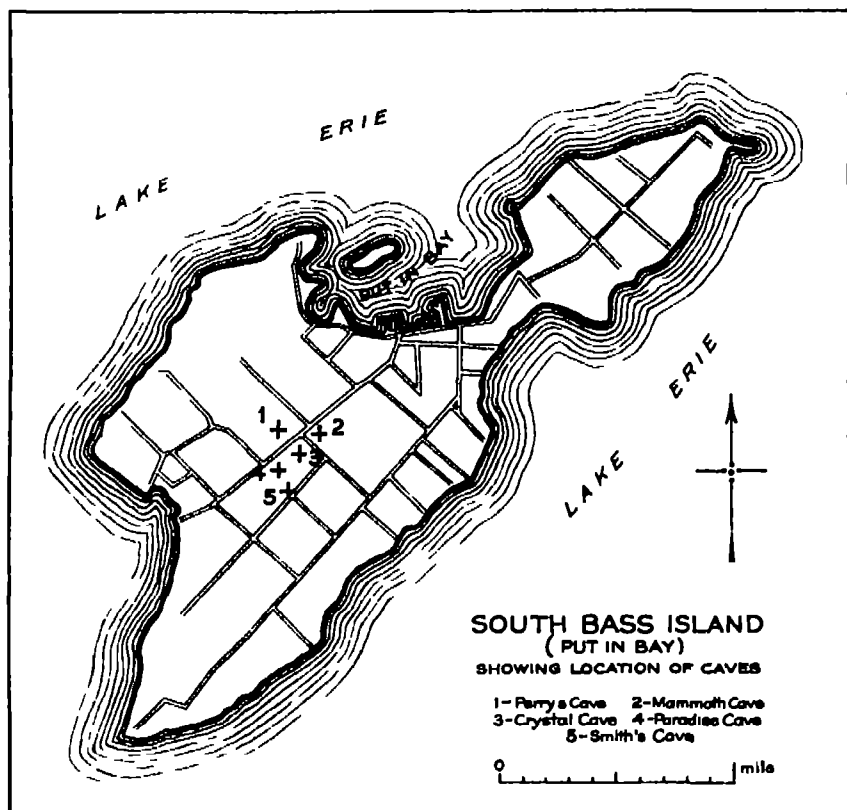
Considerable historic interest attaches to the island in that Commodore Oliver Hazard Perry used Put-in-Bay as a base for his fleet during a part of the war of 1812 It was from this harbor that he sailed for the memorable Battle of Lake Erie on August 12, 1813 The largest

¹Hovey, Horace G "Celebrated American Caverns," pp 18-21

²Carman, J Ernest, Personal communication, May 14, 1925

cave on the island is called Perry's Cave, because it is popularly supposed that it was discovered by him, and used as a powder magazine

The drainage of the entire island is underground, showing that the limestone is honeycombed with subterranean passages. Several openings are known which give access to caves, four of which are of sufficient size and importance to be attractive to the thousands of tourists who visit

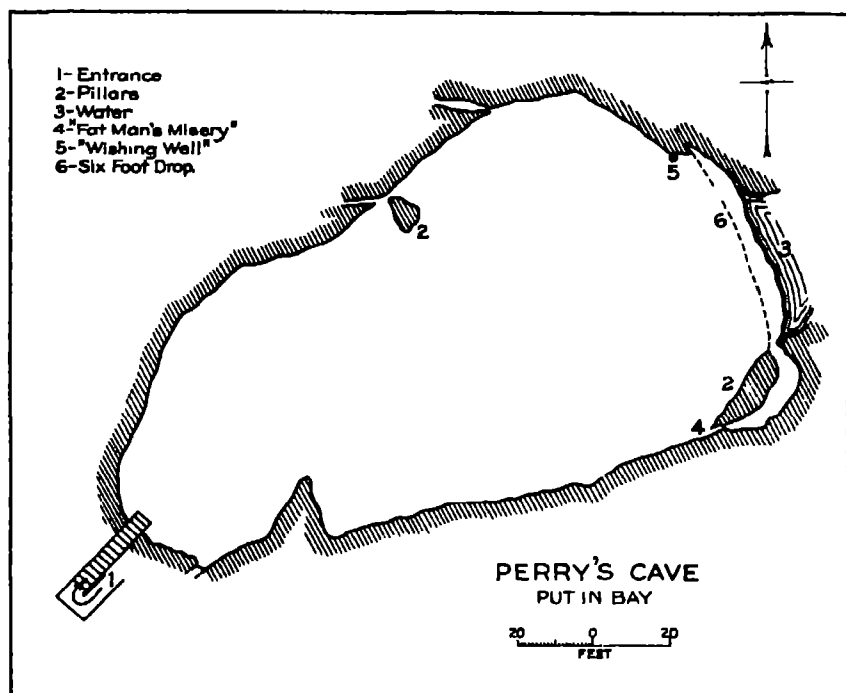


the island during the summer. These have had steps built to facilitate entrance, are electrically lighted, and during the summer have guides to conduct visitors. In addition to the four caves which are regularly open there are several others which are smaller, and which are not often visited. Some caves which were known at one time are no longer open, the entrances having been filled by natural means, or in some cases by the owners. An opening into a cave is usually regarded by a farmer as a liability, on account of the danger to stock, and consequently many have been filled up. The origin of the caves will be discussed after the descriptions

PERRY'S CAVE

Perry's Cave has the most traditional and historical background of any on Put-in-Bay Island. It is located about three-fourths of a mile southeast of the harbor, near the public road. The entrance is covered by a large building, formerly used as a dance hall. The entrance has been much enlarged, a concrete stairway affording means of descending into the cave the floor of which is 31 feet 6 inches below the surface.

The cave is roughly oval in shape. It is highest near the center where the roof is nine feet above the floor. To the northeast the floor



descends sharply for six feet and farther on water covers it. This was not measured but it is reported to be 65 feet deep. About 40 feet farther to the northeast the roof meets the water. Interesting to report, the water in the cave rises and falls with that of the lake, in each it stands about two feet higher after a strong northeast wind. Heaping up the water along the shore increases the pressure and this raises the water level in the cave, but no circulation was observed in it. Water is constantly dropping from the roof.

The floor and roof were at one time covered with stalactites and stalagmites, but all of the former and most of the latter have been removed. The few remaining stalagmites are rather large, and to this fact they probably owe their preservation. The roof is covered in most

places with a deposit of travertine, and the floor in some places has more than a foot of this material. The floor and roof are rather flat, any local undulations of the floor being matched by corresponding ones in the roof, that is an elevation of the floor has a corresponding depression above it and likewise a depression of the floor has a projection in the overhanging roof. At the northeast wall, marked "Fat Man's Misery" on the map, a large block of stone has fallen from the roof, one end resting on the floor, and the other remaining against the roof. One end of the rude archway thus formed is rather narrow, hence the name.

The attendant and caretaker of this cave, John Gangwisch, has lived 53 years on the island, and has held his present position for the past 39 years. He places no credence in the popular story that Commodore Perry hid his troops there before the memorable battle in 1813. It is probable that Perry knew of the cave, and may have stored some of his supplies there during the time his fleet was anchored in Put-in-Bay. Nevertheless the cave would seem to be a very damp place in which to store gunpowder. Mr. Gangwisch found several arrowheads, stone axes, and two stone pipes under a stalagmite which he removed years ago, indicating the use of the cave by Indians, thus definitely disproving the tradition of the original discovery by Commodore Perry. However, his reported association has given the cave its name. The cave is visited every year by thousands of people. Electric lights are provided, and an admission fee of twenty-five cents is charged.

Mammoth, Crystal, and Paradise caves, owned by Mr. Gustav Heineman, are located just across the public road from Perry's Cave, the entrances being within two hundred yards of each other.

MAMMOTH CAVE

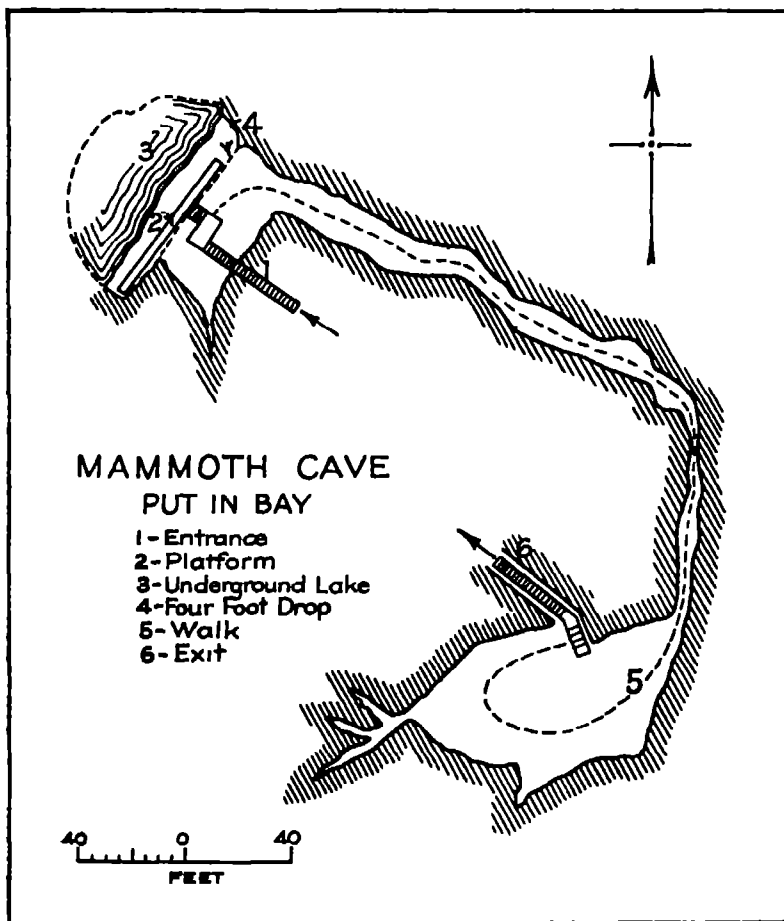
The presence of Mammoth Cave has been known since the coming of the white man to the island. Indications of its use by the aborigines will be mentioned later. This cave has two openings, tourists enter at one and depart at the other. The northwest opening measures 36 feet vertically, and at a point indicated on the map there is an abrupt descent of eight feet more. Ten feet beyond this is the shore of what is popularly called an underground lake. The water deepens gradually, the roof and water meeting about 65 feet to the west. The level of the water rises and falls as it does in Perry's Cave.

The cave has the shape of a very broad U, with directions and dimensions as indicated on the map. Very little water drips from the roof. The entire cave has a very gentle slope towards the water. The floor is only 16.8 feet from the surface at the southeast entrance, in contrast to the 44 feet between the floor and the surface of the ground at the northwest opening.

The roof is covered in many places with a deposit of travertine. A few small stalactites, mostly one-half inch in diameter and two inches long, are present. The stalagmites are not nearly so numerous, but are much larger, as is generally the case. Some of these have been assigned fanciful names, according to their supposed resemblance to an animal, such as "Alligator," "Turtle" etc.

The height of the cave averages from three to four feet, except at the east entrance, where it is 15 feet. A pathway has been excavated to a

depth of from two to three feet so that visitors may walk upright except in one or two places. The floor is very slightly rolling, and evidence seems clear that floor and roof must at one time have been together, because the shape of the floor is the opposite of the roof. This is one of the most striking features about the caves on the island, and will be discussed farther on.



Formerly, according to Mr Heineman, the underground water was the only source of good water on the island. This cave must also have been known and used by the Indians, because Mr Heineman reports finding many fish and animal bones, as well as deposits of ashes in it. The cave is shown to thousands of visitors annually. It is lighted electrically and is provided with guides. An admission fee of 20 cents is charged.

CRYSTAL CAVE

Crystal Cave is the most unusual on the island because of its deposits. It consists of two small connected rooms and was discovered by Mr Gustav Heineman in 1891 when drilling for water. The entrance is about 200 yards southwest of Mammoth Cave, and a plank stairway descends to the floor, which is 30 feet below the exterior level. The cave had an original height of about three feet, but the floor has been excavated so that visitors may stand upright. The cave is dry, even during rainy seasons very little water enters it.

The walls are completely covered to a depth of two feet in most places by beautiful blue celestite crystals (SrSO_4). These are very large, usually ranging from eight to fifteen inches in length. They are tabular in form, and belong to the orthorhombic system. The crystal faces are brachypinacoid, prism, brachydome, and pyramid. Some crystals are attached to the matrix by only a corner or edge, and then show the entire crystal form. The appearance of the interior of this cave is that of an immense geode. The crystals, removed from the floor when it was deepened, were sold to fireworks manufacturers for the strontium.

Because of the covering of the interior of this cave, it is impossible to ascertain if the floor and roof "fit," as they do in the other caves of the island.

PARADISE CAVE

Paradise Cave is only about 200 yards west of Crystal Cave. It is not large, about 30 feet wide and 125 feet long. The entire cave dips 25 degrees southeast, and ten degrees northcast. The height is from three to five feet, but in some places a little more than a foot of the floor, which is 24 feet below the surface, has been removed for a walk.

Water drips from the roof and is always present in the lower part of the cave but its depth is only two or three feet. The water level, as in other caves of the island, fluctuates in wet and dry seasons.

This cave has more stalactites than any other on the island. In fact nearly the entire roof is covered with them or travertine. The largest is advertised to be 36 inches in length, but the others are very much smaller. The floor also is nearly covered with travertine. A few pieces of fallen rock from the roof were found.

As in the other caves of this group the floor and roof at one time seem to have been together. The explanation for this phenomenon is the same as for the other caves on the island, and it is offered elsewhere.

Many tourists visit this cave during the summer season, but according to Mr Heineman, it is not as popular as either Perry's, Mammoth, or Crystal Cave. It is electrically lighted, and an attendant is present in the tourist season to act as guide. A wide plank stairway leads from the shelter house at the entrance into the cave. A unique feature is the strong netting on either side of the walk through it. Inasmuch as this is the only cave on the island that has not been despoiled of its stalactites, the owner desires to keep it intact, and this means is taken of doing so. An admission fee of ten cents is charged. Probably this cave has been known from the time that the island was settled.

SMITH'S CAVE

In the front yard of the property owned by Tillie Smith, a quarter of a mile south of the caves on the Heineman property, there is an entrance to a small cave which has been walled up four feet square with rough stone to a depth of five feet. From the bottom of this well-like entrance, the cave extends downward at a 25 degree angle for about 50 feet. The length is approximately 150 feet, and the width from 50 to 60 feet. Exact measurements were impossible on account of the very low roof near the limits of the cave. The greatest length is north 10 degrees west. The maximum height is five feet, but through much of the cave it is decidedly less. The cave is dry, but in rainy weather some water must find its way in it for small stalactites, usually three inches long and one-half inch in diameter, are present in abundance. The floor, as well as the roof, is almost covered with travertine, an unusual condition because in the other caves some of the floor has been excavated to form pathways and hence the travertine removed, so that visitors could walk upright.

The floor and roof match each other distinctly, that is an elevation below has a depression above, a fact that is more readily observed in this cave because of the lack of alteration by digging pathways and building stairs. Several narrow passageways lead farther downward, but these are too small to permit exploration. It is probable that they lead to water, thus furnishing a means of drainage. No use is made of this cave, nor are data available as to its history or discovery.

OTHER CAVES ON PUT-IN-BAY ISLAND

The presence of sink holes over the entire island indicates the presence of more caves than are now known. As stated previously, some entrances have been closed. Cottingham¹ mentions two, one on the property of James Duff, and the second near Hotel Victory, but neither was found by the present writer. Since Cottingham visited the island, Hotel Victory has burned, and now (1924) the extensive and once beautiful and park-like grounds have grown up with brush and weeds. The depressions and sink holes are used as a dumping ground for rubbish by the whole island.

ORIGIN OF THE PUT-IN-BAY CAVES One of the most noticeable features of the caves on the island is the one already mentioned in which the floor and roof seem to "fit". In other words, the cavity does not appear to have been formed by solution of the limestone in the usual manner that most caves are, but because the floor and roof, which at one time were in contact, have been separated. The cause of the separation has been assigned by Kraus² and Cottingham³ to the change of layers of anhydrite (CaSO_4) in the rock to gypsum ($\text{CaSO}_4 \cdot 2 \text{H}_2\text{O}$). It is then supposed that the gypsum which is soluble in water⁴ was removed, leaving the space of the present caves.

¹Cottingham, Kenneth, Ohio Journal of Science, Vol XX, No 2, p 38

²Kraus, Edward H., "On the Origin of the Put-In-Bay Caves," The American Geologist, Vol 35, pp 167-171, 1905

³Cottingham, Kenneth Ohio Journal of Science, Vol XX, No 2, p 38

⁴One part of gypsum in 483 parts of water, Kraus p 170

The expansive force generated by the hydration of anhydrite to form gypsum is very great, and according to Bischof¹ has often been instrumental in deranging stratified rock. According to the exceedingly conservative estimate of Credner² the expansion is 33 per cent when the anhydrite changes to gypsum. Other authors place this expansion as high as 62 per cent.³ Taking the lowest figure, which is more than three times the expansion of water when it changes from the liquid to the solid state, it seems that such force must be enormous and perhaps sufficient to separate beds of stratified rock.

This is the only explanation advanced to account for the formation of these caves, but positive proof of this does not seem to the present writer to have been established. No gypsum is found in the caves. They do not show separation along any bedding plane, with the possible exception of Perry's Cave, but rather separation along gently dipping cracks which however are very irregular.

It is possible that former caverns have existed below the level of the present caves and that the roofs of some of these have collapsed. The level of the lake conceals any evidence that might be obtained along this line, for water is present in the lower parts of almost all of them.

To summarize. These caves referred to as the "Put-in-Bay type" have not been formed by solution of the limestone by percolating ground water. Their floors and roofs were at one time in contact and later were separated. If the roof was raised the application of some agency, such as the hydration of anhydrite to form gypsum, and the subsequent solution of this produced the caves, while if the floor dropped, some action has operated from underneath, evidence of which is now concealed by the waters of the lake.

CAVES IN CRYSTAL ROCK PARK

Crystal Rock Park is in the northwest corner of Margarettta Township, Erie County. It is marked "Crystal Rock Spring" on the Bellevue Quadrangle, and is located eight miles west of Sandusky, and three-fourths of a mile south of the Lake. The park is owned by Edward J. Martin who operates it for picnic, summer resort, and dance hall purposes. The portion lying nearest the Lake has been allotted for summer cottage sites. One of the features of the park is Crystal Rock Cave.

CRYSTAL ROCK CAVE

Crystal Rock Cave is the only one in the park which is regularly shown to visitors. It is in the Put-in-Bay division of the Monroe dolomite which is fairly thick bedded, massive, and apparently non-fossiliferous.

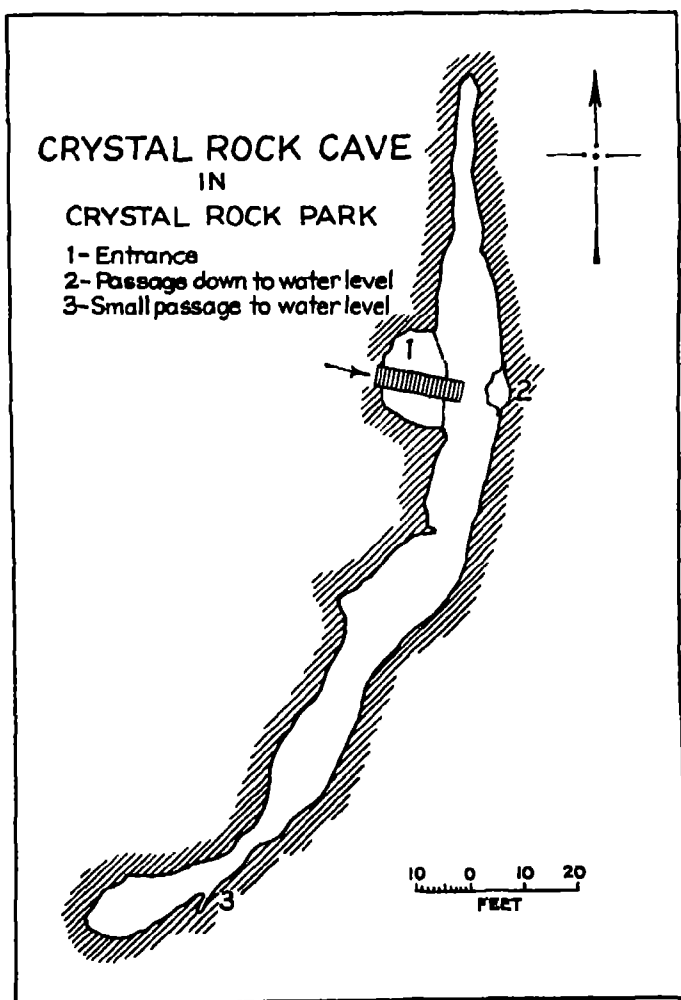
A flight of concrete steps leads into the cave. The entrance is 17 feet square, and it is 16.5 feet from the floor of the main room to the level of the ground above. The entrance was originally a sink hole, which has been blasted out to make a larger opening. There are several other sink holes in the vicinity.

¹Bischof, Gustav, *Elements of Chemical and Physical Geology*, English Translation p. 428.

²Credner, Hermann, *Geologie* Neunte Auflage, p. 96.

³Kraus p. 168.

The main room is approximately 40 feet long and 20 feet wide, and is the only portion ordinarily visited. Here the roof is from four to six feet high. Directly opposite the entrance is a narrow passage about 30 feet long, which descends about 10 feet vertically in that distance.



Beyond the narrow entrance this passage widens a little, being large enough to hold a small electric water pump and pressure tank, which supplies water to the park. The water is obtained from the lower end of the passage, where it is said to be always present.

Running north from the main room is a small passage 30 feet long and averaging two feet in height. It is nowhere more than five feet

wide and leads very slightly upward. To the south a low broad crevice extends about 100 feet. In places this is only a foot high, two and one-half feet being the maximum. This passage is inclined, water being encountered at the lower end.

The drainage of the region is underground, and this cave receives its share. The water collects in the lower portion of the cave, where the water table is visible. But little drips from the roof and hence the cave is not very wet.

The roof is not covered in more than half the area by travertine deposits. These range in thickness from a thin coating to an inch or more. A few small stalactites are present, the usual size being a quarter of an inch in diameter and about two inches long. Still fewer stalagmites exist, these being larger than the stalactites. On the whole, the floor is bedrock, or bedrock covered by loose pieces of stone fallen from the roof. In no place was the floor muddy.

The floor and roof are exact casts of one another. As elaborated elsewhere in the general discussion of caves of this group, the floor and roof must at one time have been in contact.

The cave is visited by hundreds during the summer season, and a charge of ten cents for admission is made. The father of the owner, Mr. Martin, one of the pioneers of the region, is in charge of the cave, which is lighted by electricity.

BREWERY CAVE

Brewery Cave is the other one in Crystal Rock Park. Its entrance is to the south of that to Crystal Rock Cave. Water from this cave was formerly pumped six miles to the Crystal Rock Brewery in West Sandusky, it being claimed that the water imparted superior qualities to the beer. However, before the Eighteenth Amendment closed the plant, it had discontinued the use of Crystal Rock water.

A brick-walled excavation, 21 feet in depth, and 14 by 10 feet, served as an entrance to the cave, and to house the pump and engines used to force the water to Sandusky. From the entrance an eight-inch pipe leads to the water, popularly called an underground lake. The pipe remains but the pumps and engines have been removed.

At the bottom of the entrance a passageway about two feet high leads into the main cave, which is divided into two parts by a large block of stone which dropped from the roof. The cave is nowhere more than four feet in height and tapers at the sides.

The cave dips northeast at a slight angle. Water is present at the lower end. A little water drips from the roof, and the floor is therefore damp.

There are no deposits in this cave, the roof consisting of bedrock and the floor being covered in most places by pieces fallen from above. These are angular blocks of varying sizes, one as noted above being sufficient to almost close one end of the cave. The floor is almost flat, and is covered with loose rock. The floor and roof at one time appear to have been together. This again is a cave of the type in which the floor was depressed or the roof elevated.

GOOD'S CAVE

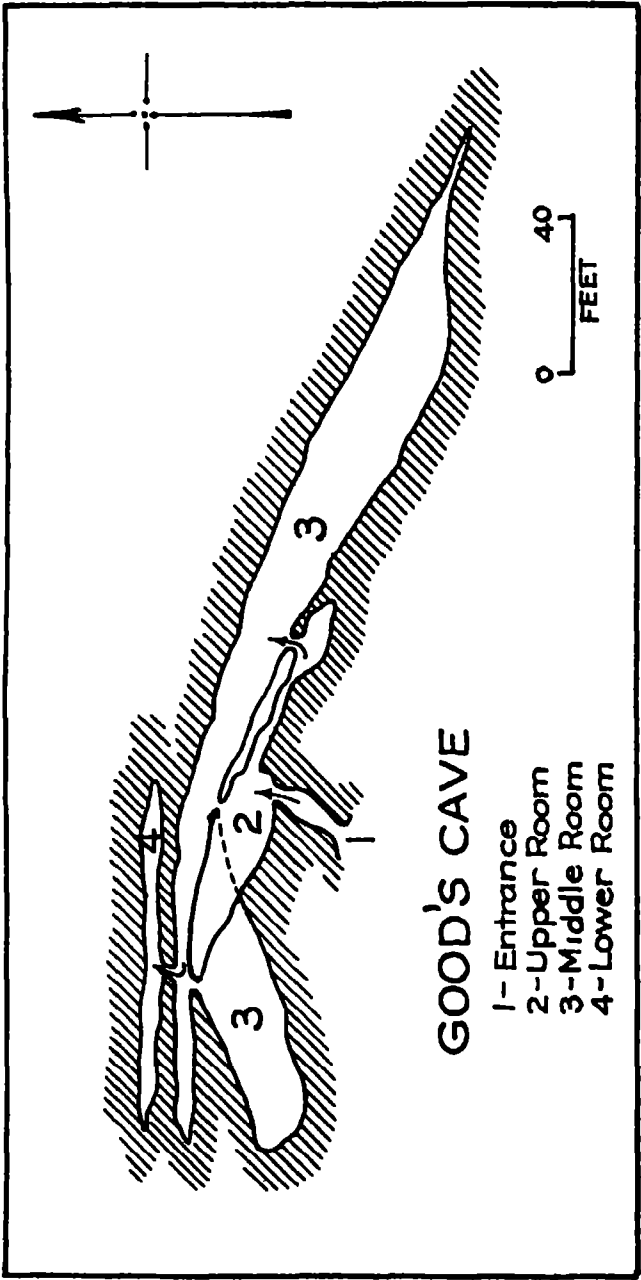
Good's Cave is in the northwest corner of Section 14, Thompson Township, Seneca County. It is about a mile southwest of the village of Flatrock, and four miles south of Bellevue, on the farm of Emanuel Good. The bedrock is crystalline, thick-bedded Columbus limestone. This cave is the third largest known in Ohio, and in addition, is the only one with three distinct levels.

The Entrance The entrance is about 30 feet south of the public road running east and west along the north side of Section 14. It is not from a distinct sink hole, but rather from a fissure which intersects the surface. The cave is not the usual solution type, neither is it quite of the Put-in-Bay or Crystal Rock variety. The drainage of the whole region is mostly underground, the bedrock being fissured and shattered, and this cave seems to be simply a larger fissure. The surrounding country is a very gently rolling, almost flat, glacial plain, which has, as is usual in regions of young topography, rather poor natural drainage. The fields which are cultivated are tiled, the drains running to the lowest places where the fissured bedrock takes care of the water. Mr. Good, owner of the cave, states that even in prolonged wet seasons this means of drainage is very efficient.

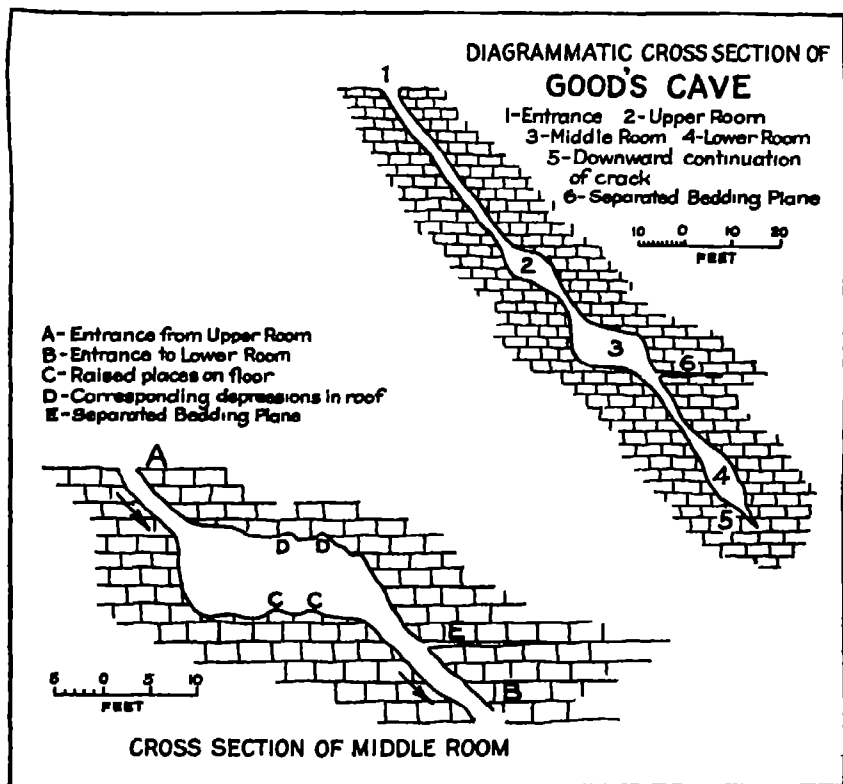
The crevice at the entrance is only large enough to admit a man, being five feet wide and three feet high, it dips 55 degrees, north 15 degrees west, and has a strike north 75 degrees east. This narrow passage extends 50 feet downward, where it enlarges into a chamber called the Upper Room.

The Upper Room This is 12 feet wide, 8 feet high, and 105 feet long, the length being in a general east-west direction. The floor of the Upper Room is not level, but dips in the same general direction as the fissure. The floor is covered near the entrance with clay washed in from the opening, the deposit resembling a small alluvial cone. This is clearly not residual, because such deposits are found nowhere else in the cave, and the course of the mud can be traced from the entrance into this room. Throughout the remainder of the room the floor is more or less covered with blocks fallen from the roof. Because of the clay and broken stone on the floor, it is not possible to prove that the floor and roof were at one time in contact, but such must have been the case because indisputable evidence exists in other rooms and passages, which will be described later. No deposits from percolating ground water exist in the Upper Room, the bedrock being fresh looking and unweathered. The same condition prevails throughout the whole cavern.

The Middle Room From the Upper Room several passages lead to the room below but only one is large enough to permit of entrance. This is 10 feet wide and leads down 25 feet vertically, mostly over broken rock. At one time the passage between the Upper Room and the one below was continuous along the north side, but blocks of rock have fallen from the sides and roof into the narrow rift, choking it so that entrance to the room is possible only at this place. The second chamber, called the Middle Room, is the largest, being 225 feet in length, 20 feet in width, and having an average height of eight feet. This chamber extends almost north and south in a straight line, but



divides 60 feet from the west end. The most southerly of these is the larger, as shown on the map. The floor and roof are irregular and jagged although they are rather level, except at the extreme east end, where the whole chamber rises slightly. The irregularities of the floor fit those of the roof, that is, a depression in the roof has a corresponding elevation on the floor immediately below. Some loose blocks on the floor have fallen from above, but otherwise the floor and roof are bare. Two small



stalactites, the size and shape of a cigarette, are present near the entrance to the lower room but these are the only travertine deposits in the entire cave.

The Lower Room. The fissure which continues downward 40 feet at the usual dip of 55 degrees is so choked by pieces of rock from the walls that entrance from the Middle Room to the lowest can be made only at one place. About five feet below the floor of the middle room, along the north wall of the fissure is an opening which measures 15 inches at the fissure, but gradually decreases 30 feet northward where the beds again come together. The cross sections shown illustrate this. The bedding plane along which the opening occurs is evident on the

south wall, immediately across the fissure, but separation has not taken place there, proving that no movement or faulting has occurred. Throughout most of the forty feet that the fissure continues downward the walls are about six feet apart. Forty feet from the floor of the Middle Room, a vertical distance of 34 feet, the crack enlarges somewhat, forming a small room 75 feet long, and varying from only one or two feet to several feet wider than the opening above. This is called the Lower Room. The cavity continues downward below the floor of the Lower Room, but is much narrower and so choked by fallen rock that further progress is impossible.

Various Features When visited the cave was dry, but Mr. Good states that in rainy seasons water stands in the Lower Room and in very wet weather in the Middle Room. He says that twice within his knowledge the water has risen to within a few feet of the entrance but has very quickly receded from this high mark. The water must flow in through cracks rather than from the entrance because the level rises quickly and falls quickly. The clay that is present in the passage from the entrance to the Upper Room seems to have been a gradual accumulation, rather than having been washed in by water. If the water partially filling the cave in wet weather came in through the entrance clay would be more widely distributed through it. The only travertine deposits are the two small stalactites mentioned in the description of the Middle Room so it would seem that the amount of water seeping into the cave through the limestone is negligible. That flowing into the cave must sink to deeper levels, and it may appear at the surface in the Blue Hole at Castalia, fifteen miles to the north.

This cave was not formed by solution, but by the separation of the walls of a fissure which might have been an irregular joint-plane. There can be no doubt that the walls were at one time in contact, because bedding planes can be traced from one wall to the other, and the raised places in one wall fit into corresponding depressions in the other. No faulting has taken place for bedding planes can be matched exactly at the same level from wall to wall.

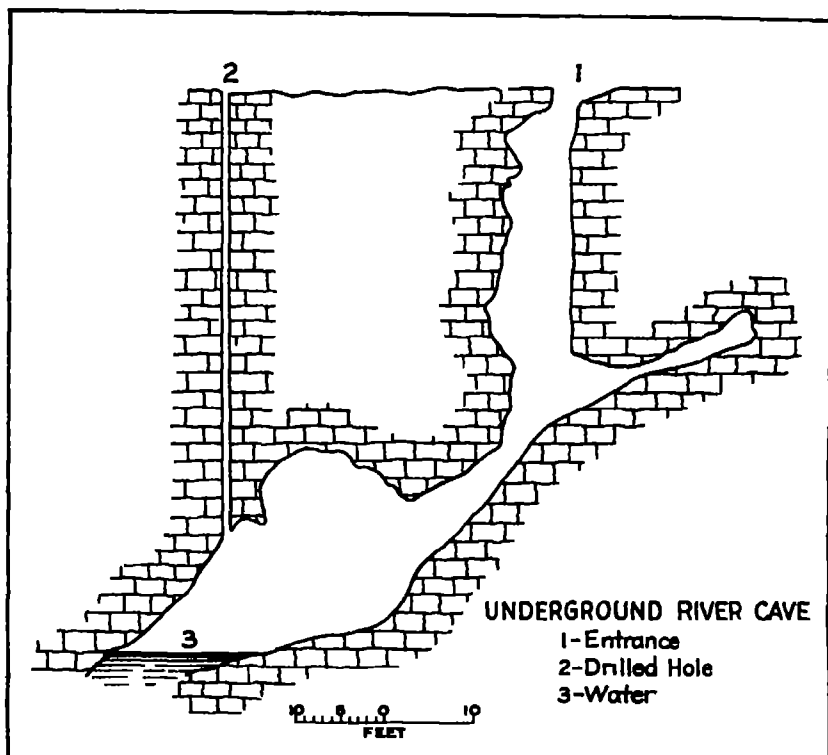
Although this is one of the larger caves of the State, it is not regularly open to the public. It is away from the main line of travel and has no trees near by which would bring people to the locality for outings or for picnics. On account of the rooms on three different levels, and the cleanliness and dryness of the cavern, it may be profitably exploited in the future. The present owner has no objections to persons visiting it, and several 'explore' it every season.

UNDERGROUND RIVER CAVE

Underground River Cave is in the northern part of Ridge Township, northwestern Wyandot County. It is three miles northwest of Carey, on the Carey Fostoria road. This cave is mentioned by Winchell,¹ but a complete description is not given. It is owned and operated by Mr. M. L. Kelly.

¹Winchell, N. H. Report on Wyandot County Geological Survey of Ohio, Vol. I, p. 631, 1873.

The entrance is from a summit of a ridge¹ which rises from 40 to 50 feet above the surrounding country. The bedrock is massive Niagara dolomite of Silurian age. It contains some gypsum. This cave is not the usual type with passages and rooms, but is a joint which has been enlarged. This has a dip of 70 degrees, north 55 degrees east and a strike north 35 degrees west. The vertical distance to the water in the bottom of the cave varies from 56 feet in April and May to 96 feet when the water is lowest in December and January. The width varies from



four to ten feet, and the length from eight to 20 feet, varying with the depth as illustrated by the cross section shown.

No ground water drains into the cave, but the surface of the water in it fluctuates as much as 31 feet. When visited it was 65 feet from the exterior surface, but during the winter it is reported to fall at least 20 feet below this. Many stories exist as to the depth of the water. The owner states that when it reaches the lowest mark there is a current which flows eight to ten miles an hour. It is popularly supposed that this stream comes to the surface in the Blue Hole at Castalia, 44 miles distant, but this seems improbable. The drainage of much of this part

¹Idem, p. 627

of the State is underground, the bedrock being more or less extensively fissured throughout the region. Most of the fissures are too small to admit of entrance, however, and those which are large enough have been covered or filled by farmers because of the menace to livestock.

No deposits are present in the River Cave. One cannot speak of this cave having roof and floor, but rather only two walls, which are of rock, and the clay which fills the joint at either end. Some slight movement seems to have occurred with the walls, and to some extent the material between them may be fault breccia.

This cave is lighted by electricity and plank steps lead to the water. A commodious rest house stands over the entrance. A hole has been drilled from the surface of the ground to the water in the cave which serves for ventilation and is occasionally used to mystify visitors by having someone talk from the surface to tourists below. A fee of 40 cents is charged for admission.

ZANE'S CAVERN

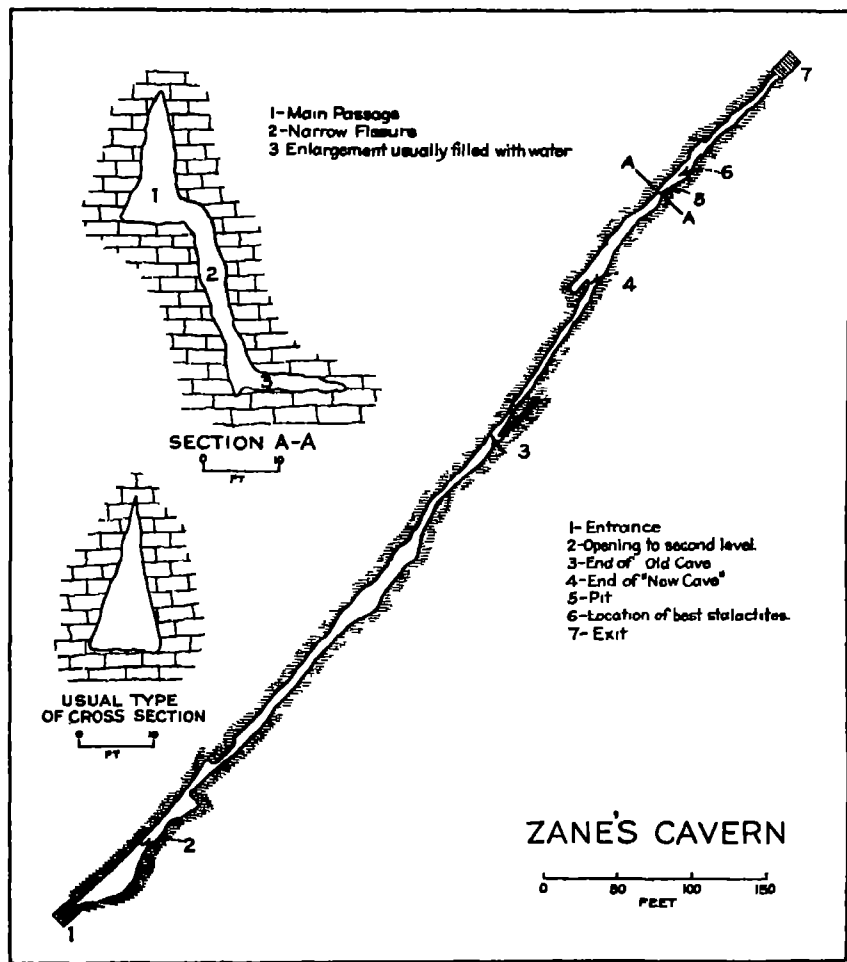
Zane's Cavern is in the northeast part of Jefferson Township, Logan County, six and one-half miles east of Bellefontaine, and three and one-half northeast of the village of Zanesfield. The cave is in the park and picnic grounds owned and operated by C. M. Richey and Sons. The bedrock is the massive crystalline Columbus limestone which outcrops in a band around the Bellefontaine outlier, on the eastern slope of which is found Zane's Cavern. At Campbell's Hill, west of the cave, on this outlier is the highest ground in the State, 1,550 feet above sea level.

The cavern extends from one side of a spur to the other in an approximately straight line, northeast and southwest, for a distance of about 800 feet. Each entrance is artificial, the original opening by which the cave was found having been covered. Until the winter of 1924-25 this cavern was really two separate ones, because for about 125 feet the passage between the two ends was little more than a crack. At that time it was enlarged so that communication between the two is now possible, and the two caves have been made into one. The two ends of the cave present different aspects because the older portion, which has been known for more than 20 years, has been robbed of all the stalactites, while the newer has all the stalactites and other crystals intact.

THE "OLD CAVE"

The opening to the southwest, which is the entrance to the "Old Cave," has been excavated 25 feet to reach its floor. A flight of concrete steps leads from the surface to the bottom. The width at the entrance is four feet but this rapidly enlarges to 20, about 35 feet from the opening. Fifty feet into the cave is a depression in the floor which is 35 feet deep and crossed by a bridge 10 feet long. From this bridge the cavern continues with a width of from eight to twelve feet for about 250 feet where a second and smaller bridge crosses a depression which was filled with water when the cave was visited. From here the passage continues 125 feet to the end of the "Old Cave." The height of the cavern in most places is from 8 to 15 feet, but at one or two points it is as much as 20 feet.

At the terminus of the "Old Cave" the passage divides, the more southerly one is very small and narrow, and after about 40 feet becomes too small for passage. Formerly the opening to the north was also very small, but this has been enlarged for a distance of 125 feet to a width of from two to three feet, and a height of from five to seven feet, where it meets the former terminus of the "New Cave."



THE "NEW CAVE"

The "New Cave" presents a different appearance in the character of the deposits from the remainder of the cavern. The height varies from 8 to 14 feet, and the width from 4 to 20. About 150 feet from the entrance the joint crack continues downward 25 feet. This was filled

with water when the cave was visited, and it is the belief of the owners, based on previous explorations when the level of the water was lower, that it leads to a passage which may prove to be another room below. This will be opened to tourists if some means of drainage can be found to remove the water. A cross section of this is shown. The northeast entrance is also artificial, leading from the surface down 25 feet to the floor of the cavern by a flight of concrete steps.

Drainage No water flows directly into Zane's Cavern, but it seeps in continuously, especially along the joint in the roof, and finds its way to lower levels. About 75 feet from the southwest entrance is a depression 35 feet below the floor of the main cavern. When visited this was almost full of water, but Mr. Richey states that in summer the water is lower, and that a passage runs an unknown distance from the bottom of this opening at right angles to the main cavern above. A stairway is being built to the bottom of this pit, so that in summer people may visit it when the water level drops. If the water recedes sufficiently parties may be taken into the passages.

At most seasons of the year water stands in the pit just mentioned, and in the depression under the second bridge referred to in the description of the "Old Cave." Water is also usually present in the hole 150 feet from the northeast entrance. It is apparent that the water in these lower levels is not all due to dripping from the roof, but must be part of the ground water of the region. For this reason the problem of drainage will be a difficult one.

Nature of the Floor and Roof Deposits The floor of Zane's Cavern which is gently undulating is at the horizon of a very prominent bedding plane which can be traced throughout the entire cavern. The surface is rather smooth, except for blocks fallen from the roof or from the walls. While not muddy the floor is damp in places, and gravel has been spread over it. This obscures the original state of the floor.

The roof in most places is very narrow, because of the inverted V-shape of the cross section of the cavern. It is covered with travertine nearly everywhere. In the older portion of the cave all of the stalactites and the smaller stalagmites have long since been carried away. Through most of the cavern the walls are covered with travertine, which ranges in color from white to deep red.

In the "New Cave" the stalactites are numerous and intact, and great care is being taken to protect them. The dripping water has formed stalagmites on the floor and in some cases stalactites and stalagmites have grown together to form small columns. Some of the stalactites are 18 inches long, and two or three inches in diameter but the usual length is not more than a foot. Some are shaped like fish-hooks, while others have grown from the roof at an angle, instead of straight downward. This is probably due to irregular crystallization over parts of the stalactite.

Origin The origin of Zane's Cavern has been by solution along the joint whose upward extension is visible at some places in the roof. Occasionally this is filled with gravel and other foreign material which has been washed in from above. The cavern has not been made by running waters, for at no place was a current observed. Part of the enlarge-

ment has no doubt been due to falling of blocks from the roof and sides of the cave

Historical and General The old portion of the cavern was discovered in 1893 by Lawrence Dunlap while hunting. The original entrance was where a small stream had cut through the roof of the cavern. This opening when enlarged was known as Unagsts Cave, and was sometimes visited. In 1922 two school boys found the opening to the 'New Cave' at the opposite side of the hill. This had been an entrance to a den used by wild animals, and through curiosity the lads enlarged the opening and crawled into the cave. Mr. Richy was the next to enter this part but it was not opened to the public until an entrance was made, with concrete steps and with a strong door at the bottom where the passage leads into the cavern, so that measures could be taken to protect the unusually fine stalactites and stalagmites. The cavern was opened to the public on May 30, 1924, and that season parties were taken into the "New Cave" and then brought out and taken into the "Old Cave". The name of 'Zane's Cavern' was given on account of the association with this region of the Zanes, famous in early Ohio history.

In the winter of 1924-25 the narrow passage that could not be traversed between the two caves was enlarged sufficiently so that now, 1925, parties will be taken in at one entrance and out at the other. This connecting of the two caves makes "Zane's Cavern" the second largest in the State.

The cave is electrically lighted and courteous guides are provided by the owners. Walks and bridges have been constructed so that a trip through it does not necessitate the wearing of old clothes and shoes. The beautiful park-like grove in which the entrance to the cavern is situated adds to the pleasure of the trip. Admission to the grounds is free, but a fee of 85 cents is charged for making the trip through the cavern.

OHIO CAVERNS ¹

The Ohio Caverns, which are the largest known in the State, are in the northeast part of Salem Township, Champaign County, four miles east of the village of West Liberty, in an elevation locally known as Mt. Tabor. It is in the park and picnic grounds now owned and operated by A. H. Smith and brother. "Mt. Tabor is an elevation 1,278 feet above sea level along the eastern side of the Mad River Valley," and is an outcrop of Columbus limestone capped by Ohio shale, to the southwest of the main portion of the Bellefontaine outlier. The cave is near the top of the Columbus limestone and at one place, near the present entrance, the overlying Ohio shale can be seen where it forms the roof.

The cavern "is approximately 1,800 feet long. Its general form is that of the letter Y, the (old) entrance being at the base of the letter, and the fork 1,100 feet from it. The passages run in a northeast direction up to the fork, where one continues along the same line and the other branches off to the north. The width of the accessible galleries varies considerably, the maximum being about fifty feet. Where this

¹Part of the descriptive matter has been taken from Hills, T. M., "Reames Cave." Ohio Jour. Science, Vol. XVI, No. 6, 1916.

wide the height of all but a small passage may be reduced from a maximum of twenty-five feet to three feet or less. The wider places are usually the intersection of two joint-planes. This is not true of the northern arm, as its rooms are the largest in the cave and occur along a single joint-plane."

The present entrance which is near the fork of the letter "Y," is artificial and was made after Professor Hills' account was written. It is near the top of the hill, and descends 30 feet from the surface to the floor of the cavern. The descent is made from inside a building erected over the opening to house the plant furnishing electricity for the cave, for an office, and for a waiting room for tourists. Parties are taken into the northern arm of the "Y," then back through the base of the letter, and out at the end. A third opening exists at the end of the northern branch, but this is not used at present (1925).

"The rooms are small and narrow near the entrance (at the base of the letter 'Y') but increase in size near the inner end. They follow a northeast-southwest joint-plane which can be seen along the roof. Solution has widened the joint-plane along layers that are decidedly saccharoidal in texture. This expanded area is usually near the roof of the Cave." The resulting cross section is usually V-shaped, that is, the width at the roof is greater than at the floor. The usual height is about eight feet, but in a few places may reach a maximum of 25 feet. "At certain places solution along bedding planes far surpasses that in the other directions, and larger rooms are * * * produced."

"At the extreme end of both branches the floor of the cave is quite muddy, due to the constant dripping from the roof, at least in part. This is due to the fact that the cave in its northwesterly course passes beyond the limit of Mt. Tabor hill, and is partly under the valley to the east of it. While the surface drainage into this valley from Mt. Tabor carries off most of the water, enough descends through the mantle rock to give an abundant supply for solution and deposition in the cave."

The floor and roof are usually level, and except in some of the larger rooms, caused by solution along prominent bedding planes, are rather smooth. In these rooms many blocks have fallen from the roof, some of which are very large. One is called the "Giant's Coffin" on account of its size and shape. A walk, of concrete in most places, has been constructed throughout much of the cavern, incidental rough places have been smoothed over, and pieces of rock removed from the pathway, thus obscuring the original state of the floor in most of the cave. The northeast end of the cavern is 35 feet lower than the southwest end, but the slope is so gentle that ordinarily it is not noticed. No pronounced changes in slope are present and no real indications of any levels below the single known one are to be found.

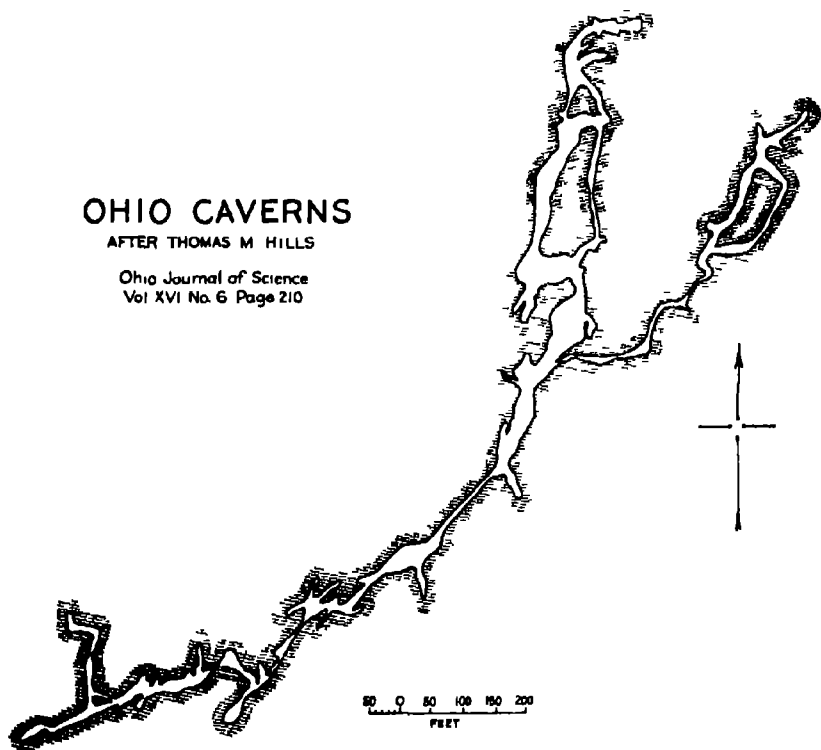
The deposits of the cave are many and varied. "The smaller stalactites are simple in form. Hundreds of them, about the size of a cigarette, are hollow, thin-walled tubes, that hang from the roof in the wider part of the cave. They are still covered and filled with water, and probably started their growth at a not distant past. The larger ones are from three to five feet long." Since the foregoing was written (1916) many of the best stalactites were removed from the main passages, indeed, most

of the cavern is quite bare of deposits except those of sheet-like character. However, in some of the side passages, especially those of the northern branch, are many fine stalactites and stalagmites. The size ranges from an inch or two in length to a foot, but a few are larger. The present owners are endeavoring to protect the remaining deposits. In many places travertine lines the walls in sheets, which are often several inches in thickness. The color ranges from the purest white to very dark red, with all the variations between the two.

OHIO CAVERNS

AFTER THOMAS M. HILLS

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"The concretions in the saccharoidal layers stand out prominently along the upper part of the walls of the cave. They vary from a few inches to several feet in diameter." These are of chert, and appear without exception to be broken across. Suggestive names have been given some of the larger concretions exposed in the walls, such as the "Beef Heart," and the "Ham."

► The cavern was discovered in August, 1897, when ground at the southwest end of the cave sank. That part of the land in which this entrance was located was owned by a Mr. Reames, and the cave was

usually known as "Mt Tabor Cave," from its location, but the owner much preferred to have it known as "Reames' Cave," and so it was described by Professor Hills. Much of the cavern, however, was under land owned by other parties, although they had no way of entering it except through the Reames' opening. Later an entrance was made at the northeast end of the "Y," and parties were taken in from there. This led to friction, but finally the present owners, A. H. Smith and brother, bought the Reames' interest, and now the cavern is run as a unit under the name of the "Ohio Caverns."

An admission charge of ninety cents is made for entrance to the Ohio Caverns. The parties taken through usually contain from ten to twenty people, with a guide at the front of the column who describes the various features of the cave, and a guide at the rear to prevent straggling, and also to protect the stalactites. A little more than an hour is required for the trip.

LAWRENCE CAVE

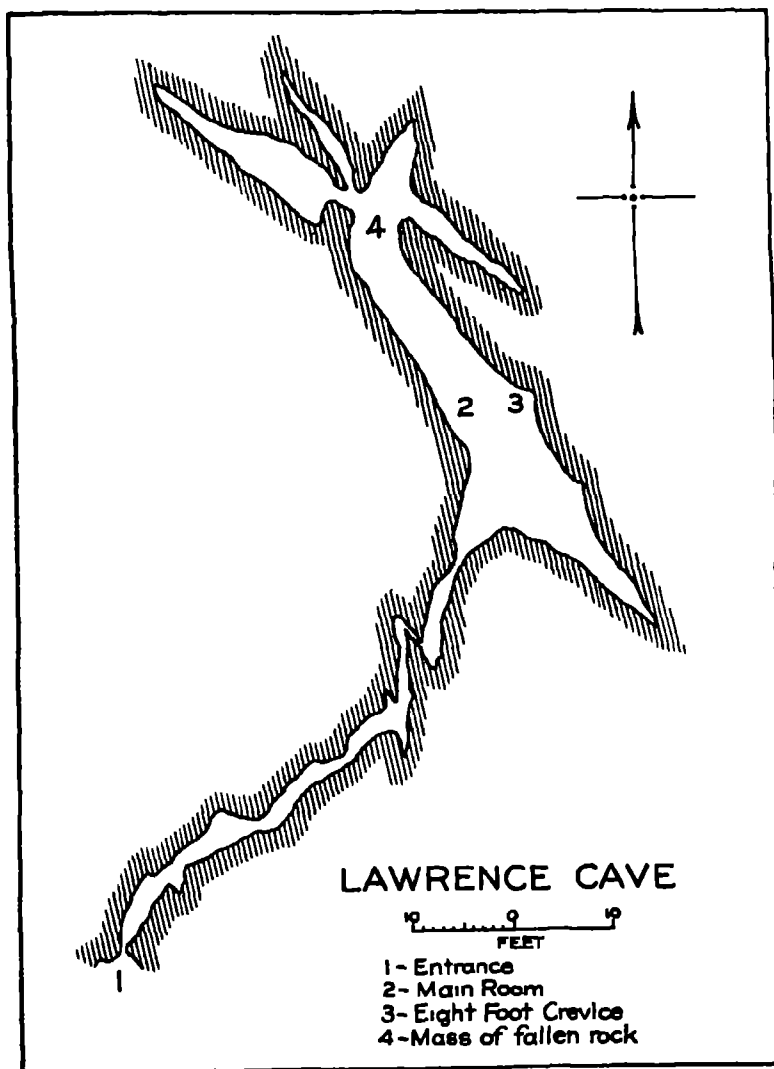
Lawrence Cave is on the Lawrence farm about one-half mile west of the Olentangy River and two and one-half miles north of Powell, Liberty Township, Delaware County. It is in the Delaware limestone, of Devonian age, which in this locality seems to be more massive and thick-bedded than is usual. On account of the clay and fallen rock in the lowest part of the cave it is not possible to tell with certainty if the cave extends through the Delaware and into the Columbus limestone.

The entrance is from one of the many sinks which are common in the region, the drainage being mostly underground. The top of the funnel-shaped opening is 30 feet in diameter and 30 feet deep. From the bottom of this a narrow crevice, which marks the beginning of the cave, leads down six feet farther to a tortuous passage which has a general northeast direction, is about 75 feet long, and which leads into the main room. This passage, which slopes gently downward, is from two to five feet wide and from six to 15 feet high.

The main room has its greatest dimension northwest and southeast. It is about 50 feet long, 12 feet wide at the greatest, and has a height of 25 feet. Directly opposite the entering passage is a crevice in the floor which is eight feet in depth, but which is too small to allow entrance. The height and width of the room decreases toward the southeast. At the northwest end a great fall of rock from the roof has almost filled the cave, so that further progress is very difficult. This point is indicated on the map. From here the cave extends about 20 feet farther in a northwest direction.

When visited the cave was muddy, but no water was present. However, in rainy weather water is said to fill the lower part. The water which finds its way in must work its way through the fissured bedrock to the Olentangy, which drains the region. The floor is covered with mud and with pieces of rock fallen from above. The roof is flat in most places, caused by a prominent bedding plane. A few small stalactites are present, but these have a muddy appearance. The floor and parts of the walls are covered with clay, some residual, and some washed in, especially in the northwest part.

The cave has been formed by solution along joints, that in a north-west-southeast direction forming the main room, and that along a less well defined series with a general northeast-southwest direction forming



the passage from the bottom of the sink to the main room. It is probable that additional caves exist in the region, but all of the other sink holes examined are filled at the bottom with debris, concealing any possible entrances.

Nothing is known of the discovery of the cave, and no improvements have been made such as stairs and electric lights. It is not visited, except by occasional students and others in search of the new and unusual. No objections are made by the owner to these visits.

THOMPSON'S CAVE

Thompson's Cave, which is small and unimportant, is on land owned by Harry Thompson, one-half mile south of Covington, in the southern part of Newberry Township, Miami County. The bedrock is Cedarville dolomite of the Niagara Series. The entrance, which is along the east bank of Stillwater River and about 100 feet from the stream, is eight feet wide at the bottom, and eight feet high. It is an inverted "V," as is the cross section of any part of the cave. The height and width decrease rapidly from the entrance for about 10 feet, where the passage enlarges into a small room about 12 feet long, eight feet wide and eight feet high. Beyond this the cave continues 25 feet farther, the width and height gradually decreasing to the end.

The cave is dry and consequently no solution or deposition appears to be taking place. The floor, which is partially covered with small pieces of rock fallen from above, is rather smooth except for these fragments, while the roof is somewhat jagged, caused by the projection of points of rock. The solution responsible for the cave took place along a joint which, in most places, can be traced upward from the roof. The straightness of the cave is further proof of this type of solution.

Because of the small size this cave has no commercial possibilities. At one time the cavern was a little longer than it is now, but some of the limestone has been quarried from the entrance for use in a lime kiln which at one time was in operation near by.

PAINTER CREEK CAVE

Painter Creek Cave is on land owned by Charles Senseman along the north side of Painter Creek, a mile west of its junction with Stillwater River, in Section 7 of Newton Township, Miami County. The bedrock is lower Niagara limestone.

The cave has two entrances, 35 feet apart, which meet and continue as a single passage. Both entrances are about 10 feet above the level of the stream and open from the bank which is vertical. The entrance to the east is arch-shaped, 10 feet wide and five feet high. The longer part of the cave seems to be a continuation of this entrance. The main passage is to the northwest for 35 feet, where after a right angle turn it continues to the northeast for 30 feet, or to the terminus of the cave. The width from the entrance to a place about 25 feet into the cave is 10 feet, there it abruptly narrows to three feet, but expands immediately into a small rudely circular room about eight feet in diameter. From this room the northeast passage continues 25 feet, gradually becoming slightly narrower, and then expands into another small room about eight feet wide, which forms the end of the cave. The height decreases from five feet at the entrance to two feet at the first constriction, it is four feet in the first small room and decreases to three in the smaller terminal chamber.

The entrance to the west is 10 feet wide and six feet high and is also arch-shaped. The passage from this is east for 24 feet, where it meets

the main cave 16 feet from the east entrance. The height gradually decreases from six feet to five. At the junction of the two entering passages a very small opening extends directly south to the bank of the stream. This is only about six inches in diameter and is straight enough for light to pass through it.

The cave is dry, and no further enlargement appears to be taking place. In flood time water is said to enter the two entrances. The creek at this place flows between rock walls, so a rise of ten feet must occur frequently. The cave of course, on account of its small size, has no commercial possibilities.

MIAMI RIVER CAVE

The Miami River Cave is near the boundary between Section 11 and Section 14 of Clinton Township, Shelby County, on the west bank of Miami River. It is four miles south of Shelby, and eight miles north of Piqua. The bedrock is Niagara in age.

The entrance is from the rock wall that borders the stream, and is only about three feet above the water level. The entrance is five feet wide and six feet high and rather arch-shaped. The passage from the entrance is 15 feet to the northwest, where the height decreases to four feet, but the width remains about six, here the passage turns at right angles to the northeast and continues in a nearly straight course for about 25 feet. The width decreases to two feet and the height is still less at the end. From the terminus of this northeast passage, the cave continues 15 feet to the northwest, the width being three feet and the height two. The end of this is the terminus of the cave.

The floor is level, but is rather rough. It is covered by mud washed in by the river when swollen by floods. The walls and roof are covered with old travertine, but no deposition is going on. When visited, the last half of the cave was wet and quite muddy. It is probable that the water backs into it whenever the level of the river becomes much higher than normal.

This cave has been formed by solution, the sharp angles suggesting joints. The cave is small, difficult of access, and wet, and hence is not of even local importance.

BUCKSKIN CAVES

Buckskin Caves is the name given to two small caves situated along the west bank of Buckskin Creek, about a mile and a half north of the village of Bainbridge, in the northern part of Paint Township, Ross County. A mile south of the caves, Buckskin Creek which flows south joins Paint Creek. The bedrock is the massive crystalline Greenfield dolomite of the Bass Island formation of the Monroe, which outcrops along the bed of the stream. It is overlain by Ohio shale, which forms the hills on either side of the creek.

The most southerly of the two caves has its entrance in the bank of the stream, four feet above water level. The entrance is six feet high and 10 feet wide. The main cave extends 32 feet west, where a small passage continues 25 feet to the south. The height decreases from six feet at the entrance to four feet midway into the cave, and contracts still farther toward the end. The entire cave rises three feet from the entrance to the terminus.

The cave is dry, but in wet seasons considerable water must flow into it for indications are present of a flow from it at times. The floor is covered with dried mud, which increases toward the inner end, showing that it is not wholly residual from the solution of the limestone, but in part at least has been washed into the cave. The floor and roof are not markedly irregular. A thin veneering of travertine is present on the roof and walls in many places. The travertine has not been deposited in the form of stalactites and stalagmites, but rather in more or less thin sheets. During flood time the water enters the mouth of the cave.

The origin has been enlargement of joints by solution and the one along which this took place to form the main cave is plainly visible above the entrance. The Detroit, Toledo and Ironton Railroad runs parallel to the stream through a cut at this place, the track being above the caves. This cut has decreased the thickness of the roof from perhaps 40 feet to 20, and gives the heavy rains a better opportunity to flow into the caves. Further, the breaking of the natural slope of the hill by the cut arrests the flow to the stream and gives it more chance to percolate into the caves. Evidence that such action has been promoted in very recent times is present in the increased deposit of mud on the floor which is unlike the residual material usually found in caves.

The second cave of this group is about 100 feet north of the first, and has the same position in relation to the stream on the east and the railroad on the west. The entrance, which is four feet above the level of the creek, is 10 feet wide. The main cave is 25 feet long and from its end a smaller passage extends 40 feet at right angles. The cave rises three feet in the first 10 from the opening, but it is level for the remaining distance.

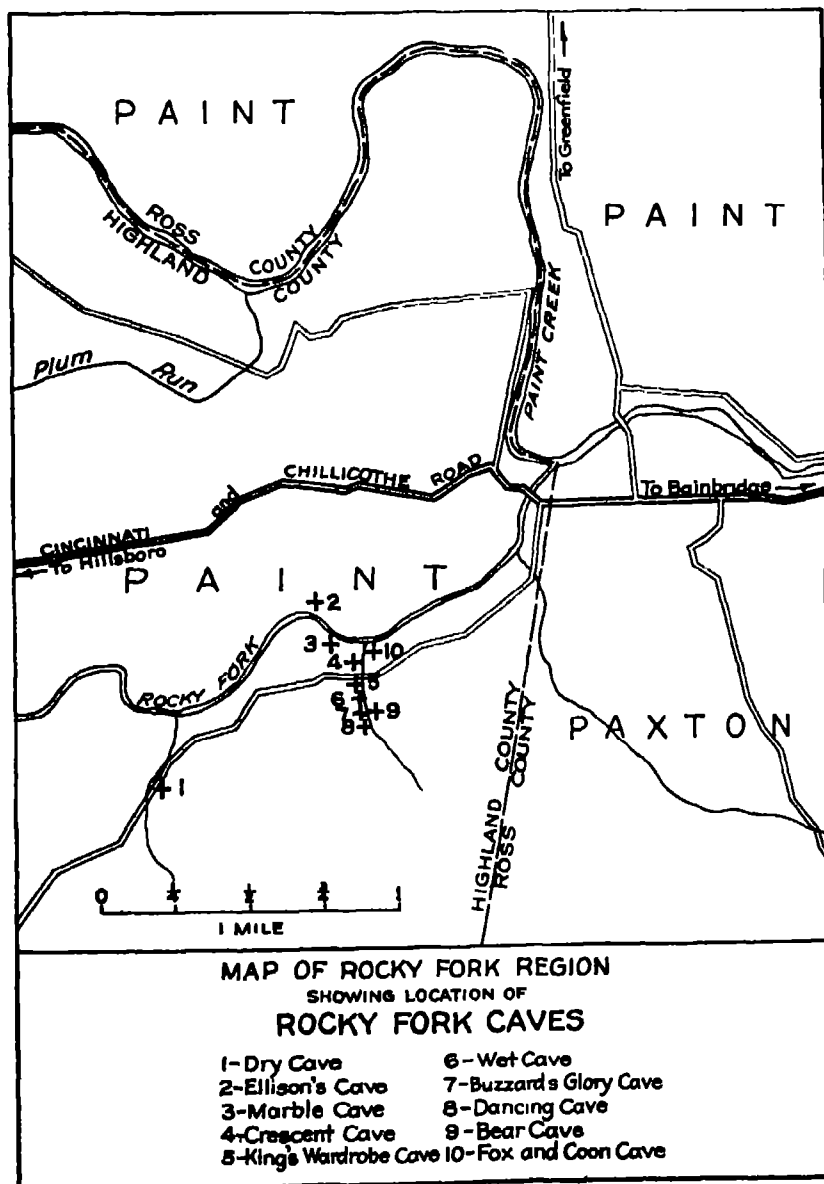
This cave, like the preceding, was dry when visited but shows the same sort of evidence of water flowing through it in wet weather. The walls and roof are covered with travertine which is much thicker and more abundant than in the one to the south. The travertine is also more weathered and in most places is overlain with a film of residual clay. The floor also is covered in the main with this material in addition to mud which has apparently been washed in. From the entrance of the main cave to the end the floor is covered with small limestone pebbles, some approaching the size of an egg. These have been partially cemented with travertine, producing a conglomerate similar in appearance to that formed in certain glacial deposits by calcareous cementation of drift, except that in the latter case the pebbles are of course made up, in part at least, of foreign material.

Buckskin Caves are seldom visited and no commercial exploitation has been attempted. Their small size and inaccessibility preclude their ever having much general interest.

ROCKY FORK CAVES

Rocky Fork Caves, the largest group in Ohio, are in the southeastern part of Paint Township, Highland County, just north of the corner of Highland, Ross, and Pike counties, along Rocky Fork of Paint Creek. The region is a wild, wooded one, a mile by dirt road from the Cincinnati-Chillicothe Pike. The land in which the caves, with the exception

of Dry Cave, are located, is owned by a group of Chillicothe business men Mr C A Ellison is the caretaker The bedrock is massive, crystalline Cedarville dolomite of the Niagara Series



Entrance to these caves varies but a few feet in altitude. The accompanying map shows the location of the entrances, most of which are on a tributary to Rocky Fork, locally known as Cave Run. The remainder are on the banks of the larger creek, which flows east at this place. Rocky Fork here flows through a narrow gorge 75 feet deep, while Cave Run flows into it through a cleft of the same depth which at places is only five feet wide, but whose usual width is from 30 to 50 feet.

There is a tradition that Daniel Boone, and a contemporary, Andrew Ellison, were the first white men to see these caverns. Unlike many where the entrances are from sink holes, and thus hard to find, these are conspicuous because they open from the sides of a deep valley. It is probable that the Indians knew of the caves, and may have occasionally used them.

The caves of this group have not been much "improved," as have most of those in the State that are operated for profit. As they are not lighted by electricity, visitors must use candles or flashlights for illumination. On the whole, these caves, although most are rather small, offer the best opportunity in Ohio to see such natural phenomena in their original and unaltered state.

BEAR CAVE

The entrance to Bear Cave, which is arch-shaped, is on the east side of Cave Run, 200 yards south of its junction with Rocky Fork. The height which at the entrance is ten feet, gradually decreases until 25 feet within it is but six feet high. The arch-like character is lost from this place, on account of the widening upward for three or four feet along the joint, which originally determined the location of the cave. A very small passage enters from the north, 60 feet from the main opening. It is also arch-shaped, three feet wide, and of the same height. As this smaller passage approaches the larger, the width decreases to eight inches, and the height increases to five feet, entering the main cavern six feet above its floor. Eighty feet from the mouth, the main entrance enlarges to form a roughly circular room, having an average height of three feet. This cavern has no noticeable dip in any direction.

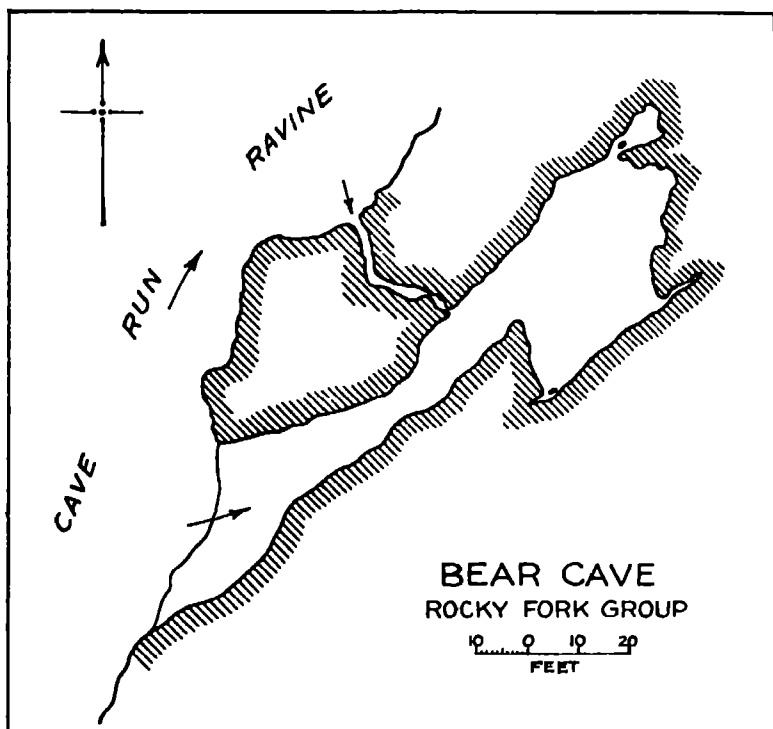
Since this cavern is dry, probably further enlargement is not taking place. The entire roof is covered with old porous travertine, and has the appearance of weathered bone, unlike the usual glossy surface of fresh travertine deposited in an active cave. The walls also a few feet back from the entrance are covered with similar material. All of the stalactites, of which only a few existed, have been broken off, except one or two small ones at the rear of the cave. As indicated on the map, one column, 18 inches high, and five inches in diameter, has been formed by the coalescence of a stalactite and a stalagmite. The floor is covered with residual clay and blocks of stone fallen from the roof. The largest of these is four feet square and three feet thick, but most are very much smaller.

The roof is irregular, the highest part being on the joint-plane along which the cave was formed. The height may reach 10 feet in this crack, with a width of only two feet, while the general height is only five feet or less. The floor is level except for the fallen blocks.

The cavern takes its name from its having been known to pioneers of the region as a bear den. It is warm and dry, and the entrance is easy of access so that of all the caves of this group it seems best suited for such a purpose.

FOX AND COON CAVE

Fox and Coon Cave is a small one, the entrance to which is about 75 feet above Rocky Fork, and at the point where Cave Run flows into the



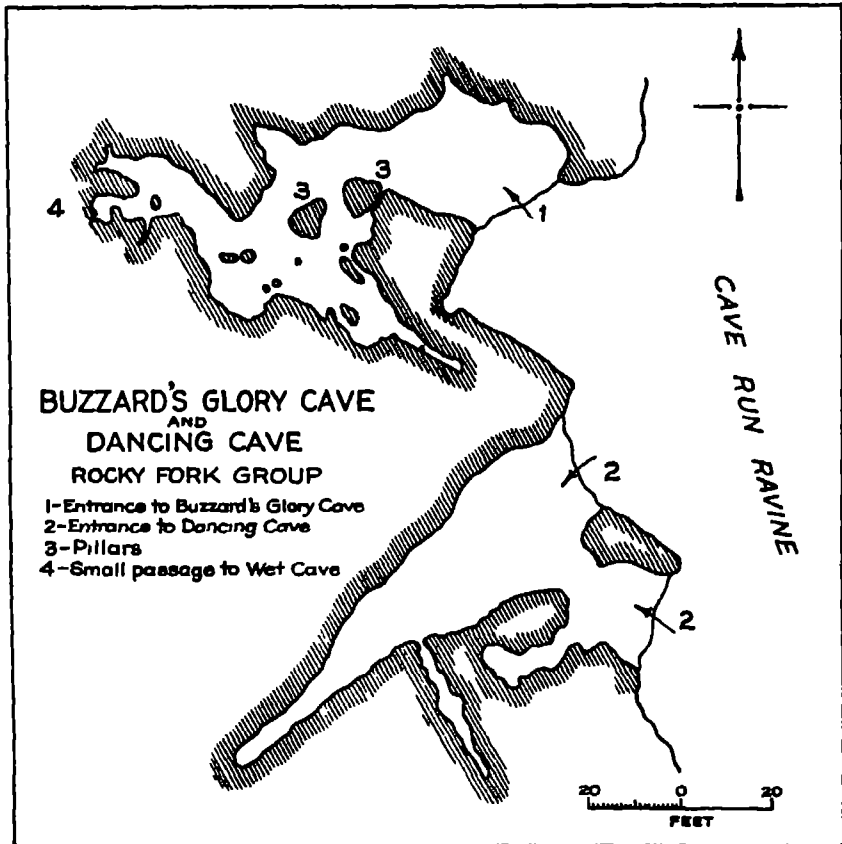
larger creek. It is only slightly more than 20 feet in length, and the greatest height is three feet. The general shape is that of a fish-hook, sloping upward 10 degrees from the entrance.

There are no deposits of consequence, the cave being dead, and no water was seen. The floor is smooth, and is covered with residual clay, which because of dryness is dust-like. This is the smallest and least important of the Rocky Fork caves. The name has been given because small animals have been known at times to make it their den.

DANCING CAVE

Dancing Cave is the farthest to the south on the west side of Cave Run, almost across from Bear Cave. It has been formed by solution along a joint-plane, the lower portion having been enlarged more than

the upper, that is, the cave is wider at the floor. This is one of the most impressive of the group, on account of the imposing vaulted entrance, 15 feet high, with a smaller entrance to the east five feet in height, as shown on the map. The cavern extends 110 feet southwest, the width and height gradually decreasing and the floor rising 12 feet from the entrance to its terminus.



Very little action is now taking place so the travertine which covers roof and walls and which at places is a foot in thickness, is dry and lifeless in appearance. The floor is covered with residual clay, and with small pieces of rock fallen from the roof. No moisture was observed in it.

The small passage which extends to the southeast from the main cave has its opening three feet above the floor of the cavern. It is very small and has been formed by solution along intersecting joint-planes. The height of the cavern decreases gradually from 15 feet at its entrance to three feet at the end. The deposits on the walls and roof are also impressive, less so however because of their lifeless appearance. It is not known how the name was acquired.

BUZZARD GLORY CAVE

Buzzard Glory Cave is 60 feet north of Dancing Cave, along the same side of Cave Run, but it is very dissimilar to that cave, being low, wide, and rather damp. Solvent action has taken place along a bedding plane, rather than along a joint. The roof is flat, and no upward extension is apparent along any fissure. The entrance is at the same elevation as that of Dancing Cave, but unlike that one it is only five feet high and decreases rapidly in the cave. The average height back from the entrance is only 18 inches, and is even less at the extreme ends.

No water finds its way into the cave under normal conditions, but in very wet seasons some must flow into it. The floor is damp but not wet. In the farthest recesses there are a few small cigarette-shaped stalactites, which are hollow, but on which no deposition is now taking place. The walls are covered with residual clay, and with small pieces of rock fallen from the roof. The pillars shown on the map are, with one possible exception, of country rock, rather than the joining of stalactites and stalagmites, as is often found in caves.

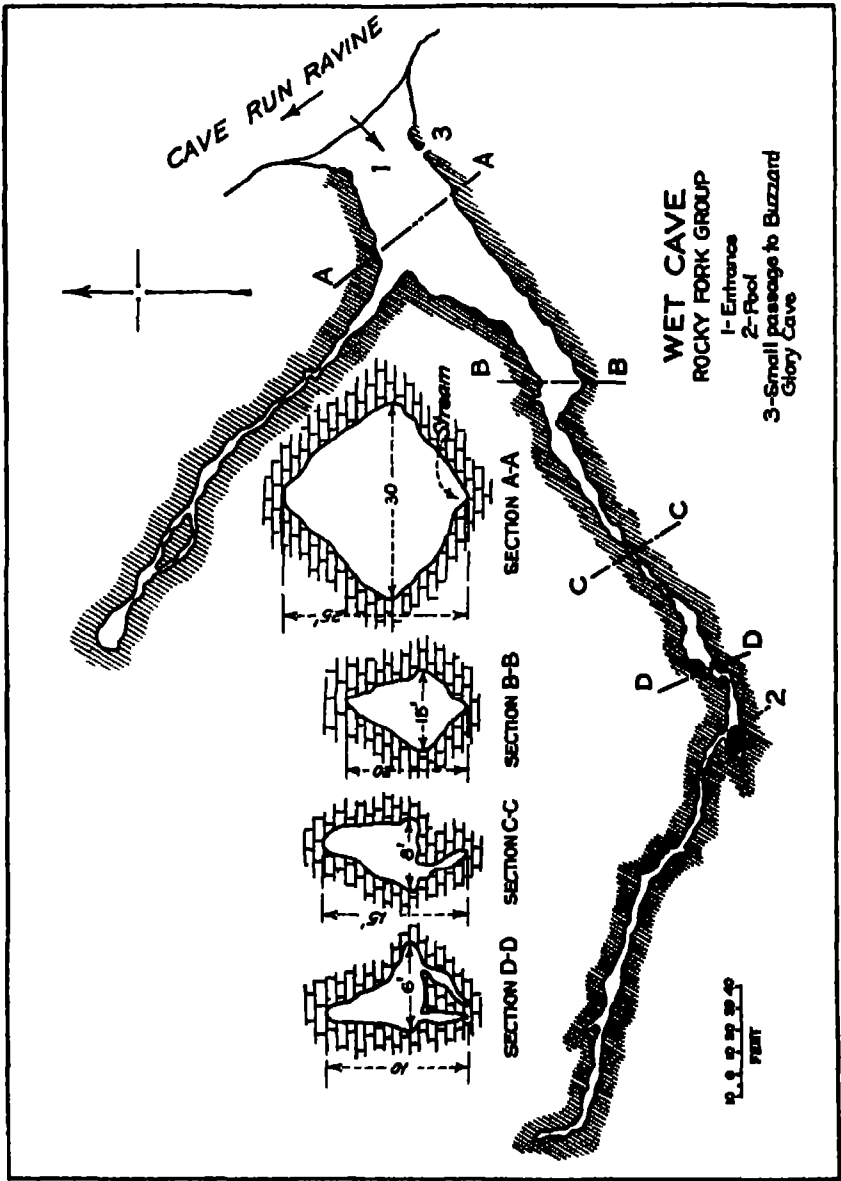
A very small passage, hardly more than a crack, a foot wide and less than six inches high, leads from the west end of this cave to Wet Cave, the next on the north. Such a passage is of course too small to admit the body of a man, although it is so narrow for only about a yard. Buzzards have been known to nest in this cave, hence the name.

WET CAVE

Wet Cave is the largest, and the only one in the group in which active enlargement is now taking place. The entrance, which is 50 yards north of that of Buzzard Glory Cave, is 32 feet wide and 15 feet high. The floor dips from the entrance 15 feet in the first 40, but the main cavern is almost level for the remaining 275 feet. At the end of the main cavern is a small room, 18 feet wide, and 15 feet high. Five feet above the floor a small passage extends 210 feet to the northwest. Near the room it is two and a half feet high, but rapidly decreases so that in the last fifty feet the roof is only nine inches above the floor.

The main cavern varies in height from eight to 30 feet, and in width from five to 40. The passage which branches off to the northwest, 40 feet from the entrance, has an average height of six feet, but is less in width. At the end of this passage is a room 15 feet wide and 25 feet long. Much clay is present here and appears to have been washed in by ground water, rather than left as residual material from the solution of the limestone as is indicated by the texture and unequal distribution of the material.

A pool of water 12 feet long and eight feet wide, the bottom of which is reported to have never been found, occupies the center of the room at the end of the main cavern. However, the beams from a focusing flashlight seem to reveal the bottom, and the writer strongly suspects that 20 feet would be an adequate depth to assign. From this pool a small stream flows toward the entrance. Water drips from the roof in many places, but the most seems to find its way into the caverns near the vicinity of the pool. The two narrow passages have a small amount of water trickling from them, more coming from the one nearer the



entrance, the floor of which is very muddy. During rainy seasons the amount of water making its way into the cave is considerable, because there are several sink holes immediately above it, one of which is 30 feet across. The water does not flow out at the entrance through an open channel, but percolates through the floor into Cave Run, 60 feet below.

The deposits of this cave are not of the usual travertine type, but consist of soft, plastic residual clay, from the solution of the impure limestone. This clay covers the floor, walls, and roof, the greatest thickness being more than six inches. While this is the largest and most interesting of the group of caves in this section, the sticky clay makes it by far the dirtiest, so that its popularity is not in proportion to its size and interest. While there are no stalactites found in the cavern, there are many projections from the roof which resemble them in shape, but on close examination these prove to be country rock left in unusual shapes by their resistance to solution.

The floor of this cave is very irregular, especially in the main cavern, where the stream has cut a tortuous channel in the rock. This has a maximum depth of seven feet, but in only a very few places is it wide enough to admit the body of a man. It offers no serious bar, however, to progression into the cavern, for the roof is ten feet above the floor in most places. The map, with its cross sections through various parts of the main cavern, shows this narrow channel sunk below the floor. This irregularity as well as the muddiness of the floor is another contributing factor to the unpopularity of this cave.

The origin of this cavern has been solution along joints, and this action is still going on, but not to the extent it once did. It is the only cave in the group which is really active. While it is the one most visited in the group, people as a rule, go but a short distance because special shoes and clothing are necessary for a trip to the pool. The name, of course, has been derived from the water in the cave.

KING'S WARDROBE CAVE

The entrance to King's Wardrobe Cave, which is 50 feet north of that of Wet Cave, is five feet high and 25 feet wide. The floor has the same elevation as the roof of Wet Cave. The cave narrows rapidly from the entrance and at a distance of about 50 feet divides into two small passages, each five feet wide. After 30 feet these reunite into a single passage which continues 65 feet farther, gradually becoming narrower and lower. The height where the cave divides is three feet, and from this point it rapidly diminishes to two, and in the last few feet is less than 12 inches.

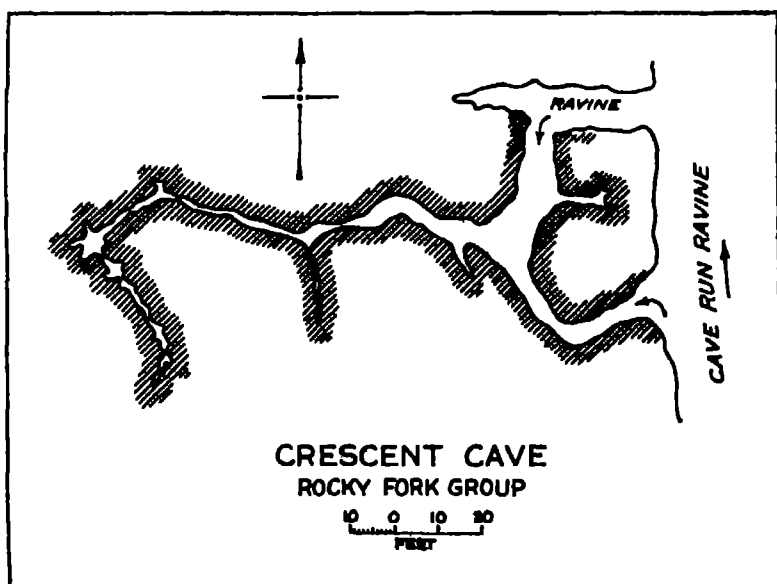
The cave apparently has no water running into it, and hence, although the floor is damp, it is not muddy. No fresh material is being deposited, but the walls and roofs are covered with old travertine. At one time a few small stalactites were present, but these have been broken off. Formerly near the entrance there was a mass of stalactites arranged in a circle three feet in diameter, having a fancied resemblance to an inverted crown. These have been destroyed, but the bases remain and still somewhat resemble a crown, hence the name. The floor and roof are essentially smooth and flat. The floor is covered with residual

clay, and with a few small pieces of rock, mostly travertine, which fell from the roof

It is probable, as shown from the configuration of the cave, and from the right angle turns, as shown on the map, that the solution has been along joints, but any enlargement upward in cracks from the roof has been masked by the thick travertine deposit

CRESCENT CAVE

Crescent Cave is along the west side of the gorge of Cave Run, just south of its junction with Rocky Fork. At this place the rock walls are perpendicular, and a walk has been fastened to the cliff so that access



may be had to the larger entrance which is 10 feet high and five feet wide, the smaller one to the north is three feet high and six feet wide. An opening connects the two and midway between them is a very irregular passage which extends 100 feet to the west, and then turns south at a right angle for 50 feet. This north-south opening is very narrow, less than a foot wide at places, and very crooked, but the height averages six feet.

Very little water finds its way into the cave, and what does, drips slowly from the roof at the farthest end, where the floor is muddy. No water flows from the cave, in fact the floor near the entrance is dry. A very little solution seems to be going on at the end of the cave, but this activity does not extend beyond the right angle turn.

Travertine covers the walls and roof in most places. No stalactites remain, but the bases of many, most of which are about two inches in

cross section bear out the statement of Mr Ellison that when these caves were first opened to the public, stalactites were broken off and carried away by almost every visitor, some removing many. The roof is uneven, extending upward along a joint crack, on which the solution has taken place to form the cave. The roof is from six to seven feet above the floor almost to the end of the cave, where the height decreases slightly. The floor of the first half is fairly regular, and is covered with residual clay, but the floor of the remainder is very irregular, and in most places is covered with more or less clay.

In the period following the Civil War a notorious bandit, McKimney by name, terrorized the countryside in this vicinity. He used this cave as a hiding place when hard pressed, and as at that time the larger entrance was inaccessible, this stronghold was easily defended, and was dry and habitable. Hence this is sometimes called "McKimney's Cave."

MARBLE CAVE

The entrance to Marble Cave is from a small tributary on the south side of Rocky Fork, about 100 yards west of its junction with Cave Run. The entrance has been enlarged upward along a fissure for a short distance and the height, aside from that caused by the joint, is five feet. This is rather uniform through most of the cave.

The floor, walls, and roof are covered to a depth of several inches with old travertine. None is being deposited at present, consequently it looks very much weathered. Stalactites at one time were quite abundant, judging by the bases present, but not one remains. The floor and roof are fairly regular, no dip in any direction being noticed.

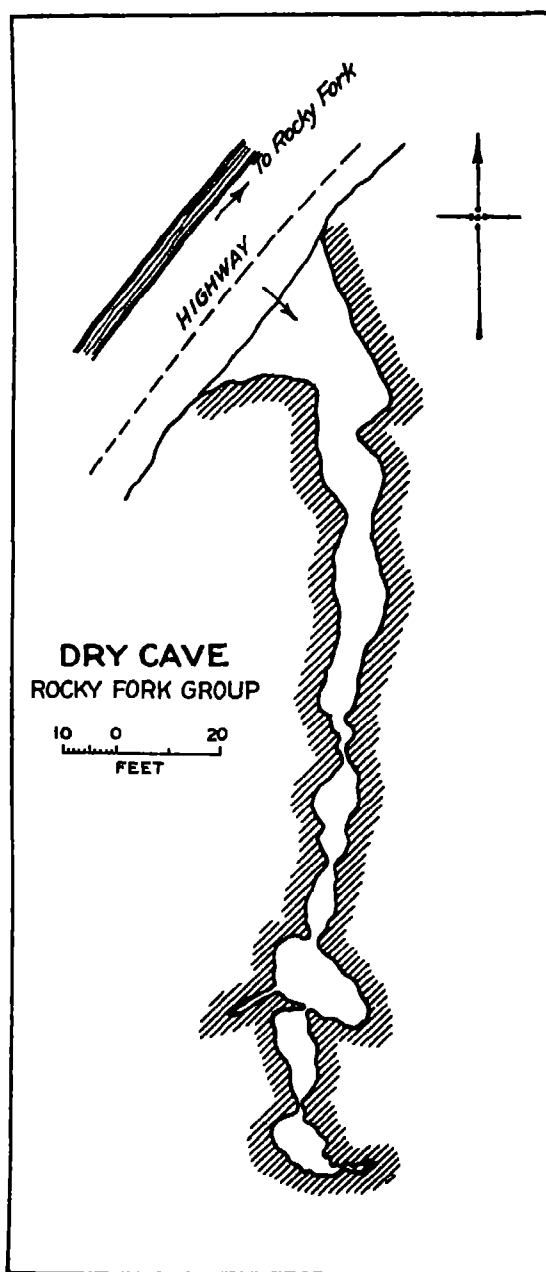
There seems to be no drainage into the cave, not even in rainy seasons. While the floor is somewhat damp, no solvent action is at work enlarging the cave. Because of the steep slope of the surface immediately above, the water runs over it into the creek, rather than into the cave, as it must have done at one time. The name has been given because of the travertine deposits, but these seem much less marble-like than those of several others.

ELLISON'S CAVE

Ellison's Cave, which is very seldom visited, is across the gorge of Rocky Fork, almost opposite Cave Run. The entrance is from the side of a small ravine, which is really a hanging valley, tributary to that of Rocky Fork.

The opening is 20 feet wide and the length is approximately 75 feet. A passage continues in an almost straight line for 60 feet, where a right angle turn is found and the cave terminates in 12 feet. The height at the entrance is six feet, and this is maintained for at least half the distance, where it rapidly diminishes to two feet for a very short distance, and then rises to three, which it maintains to the end.

Many sink holes are present on the north side of Rocky Fork, one being, as nearly as could be determined, directly above the end of Ellison's Cave. In wet seasons water flows into it, because clay to a depth of at least two feet is present at the end of the cave, and dried



mud occurs from here to the entrance, the thickness decreasing in that direction. This indicates that in rainy seasons fine material is washed into the cave through the sink hole, a part of which is then carried toward the entrance.

The walls and roof are covered with marble-like travertine in a better state of preservation than in any of the other caves of the group. While no deposition is now going on, and the travertine has assumed a weathered appearance, it has not been smoked by candles and torches of visitors, as have the other caves. The roof and walls are irregular, owing to the varying thickness of the deposits. This cave is seldom visited because of the difficulty of access.

DRY CAVE

Dry Cave is genetically related to the other caves of the Rocky Fork group. It is about a mile west of the main group, on the south side of the bank of a small stream which flows into Rocky Fork. The entrance, which is 30 feet above the stream level, is 10 feet high and arch-shaped. The cavern extends 180 feet south, almost in a straight line. The walls and roof are very irregular, partly due to the varying thickness of the deposits, and partly to the unequal solution of the rock walls. The cave rises very slightly, about three feet, to within a few feet from the end, where there is a vertical rise of four feet. The height varies from 6 to 10 feet in most places, but in one it is 20 feet.

As the name indicates, there is no water in Dry Cave, and there is no indication of any running into it even in rainy seasons. Because of this, no new travertine is being deposited so that the very thick covering on the walls and roof is dry and lusterless in appearance. This material is several feet thick on the roof at places, and indeed, the whole interior is so covered that except on the floor, bedrock is visible at very few places. The floor is covered with clay, packed hard by the many visitors. About two-thirds of the distance from the entrance, a mass of rock, similar in shape to a bunch of grapes, is pendant from the roof. It is five feet long and three feet in diameter, the sole support being two small columns of rock not more than eight inches in cross section.

This cave has apparently had its origin in solution along a joint, as shown by the enlargement upward at several places, and by its relatively straight course.

No data are at hand concerning the discovery of this cave. Whereas a single fee of ten cents to the grounds admits to all the other Rocky Fork caves, a charge of ten cents is made for visiting Dry Cave, which is under different ownership. No guides are necessary because the cave has no passages to confuse the visitor, parties procuring candles and walking to the end, or as far as they wish, then retracing their steps to the entrance.

Origin of the Rocky Fork Caves—From the preceding descriptions it will be seen that the entrance to all the caves is at nearly the same elevation, and is about 50 feet above the present drainage. Thus the water falling on the surface is carried off immediately to the streams, because of the great relief, rather than soaking through the mantle rock into the caves and flowing out through them, as must have been the case before the relief was so great.

The glacial boundary is five miles east of the caves. Rocky Fork is flowing in a post glacial gorge. In preglacial time the drainage was not by the present Rocky Fork, for observations show that this stream, eight miles to the southwest, flowed southwest, rather than northwest, as it does now. The glacier in its advance dammed preglacial Rocky Fork in its southwestward course, causing it to reverse itself, and cut its present gorge about 75 feet below the general level. It lowered its bed so rapidly that the small streams, flowing mostly from caves, could not cut down as swiftly, as is attested by a hanging valley whose stream flows from the south about midway between Dry Cave and the main group. This hanging valley is about 40 feet above Rocky Fork, and is a former cave with the roof fallen in, because at the mouth of the valley several large blocks of stone are present in the stream bed, that match, and if raised in place would fit perfectly restoring the one time arch-shaped character of the former cavern.

Doubtless the glacier, though sluggish at its greatest extension, still was able to remove a little material, and thus decreased the amount of rock between the surface of the ground and the roof of the caves, which would tend to weaken the latter. Very probably the caves along Cave Run were at one time merely branch passages from a much larger one whose position was that of the present stream. In other words, Cave Run has probably cut down through the floor of a former cavern, whose roof has collapsed.

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PARASITES OTHER THAN CESTODES IN BLACK BASS OF OHIO

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While studying the cestode parasites of large- and small-mouth bass many other parasites were found and identified. Often certain of these were more injurious to the host than the cestodes present. This was especially true of the acanthocephala which were found most often in the adult fish and in the largest numbers. No attempt will be made to give complete records for each species of parasite, but sufficient data will be included to give distribution records and degree of infestation.

TREMATODE PARASITES

Ancyrocephalus sp

This gill parasite is either *A paradoxus* (Crepl) or *A cruciatus* (Weld)

Cooper (1915, p 190) reported these species from gills of *M dolomieu*

J Stafford, 1905, reported the occurrence of *Tetraonchus unguiculatus* Wag—(*A paradoxus* Crepl) from *Ambloplites rupestris* and *Eupomotis gibbosus*

H J Van Cleve (1921, p 37) reports light infestation on gills of *Lepomis pallidus*, *Ictalurus punctatus*, *Lepomis humilis*, and *M salmoides* at the Fisheries Biological Station, Fairport, Iowa

These were found on the gills of young large-mouth bass taken in the vicinity of Put-in-Bay and West Harbor, Lake Erie. The bass varied in length from 21–42 mm. There were from 5–20 of these trematodes on the gills of the fish found infested. Only a small proportion of the fish were infested.

Cryptogonimus chyls Osborn

This form was described by H L Osborn in 1903 (p 517-536) from fishes of Michigan and New York The species was reported for *M dolomieu* from Lake Chautauqua N Y and from St Mary's River Mich It was also reported for *Ambloplites rupestris* in Canadian waters by Stafford '05

The adults of this species were found in the pyloric caeca and upper intestine of nearly all the small mouth bass large mouth bass and rock bass examined This trematode occurred as an adult first when the bass reached a size of 45-50 mm They were not found sexually mature in younger bass but were often found as skin and muscle cysts

In northeastern Ohio many young bass were heavily infested with larval cysts of this form These cysts were beneath the skin and between the fin rays Mr E L Wickliff and Mr R N McCormick report thirty six species of fish infested with these skin cysts Their collections were made in northern Ohio during August and September 1922 Their list follows

BLACK PARASITIC SKIN CYSTS (IMMATURE TREMATODES) *C. chyls* IN OHIO FISH ZOOLOGY DEPARTMENT COLLECTION OHIO STATE UNIVERSITY FISH

- 1 Common Sucker (*Catostomus commersoni*)
- 2 White nosed Sucker (*Moxostoma anisurum*)
- 3 Quillback (*Carpodes velifer*)
- 4 Small mouth Bass (*Micropterus dolomieu*)
- 5 Large mouth Bass (*Micropterus salmoides*)
- 6 Rock Bass (*Ambloplites rupestris*)
- 7 Green Sunfish (*Lepomis cyanellus*)
- 8 White Crappie (*Pomoxis annularis*)
- 9 River Chub (*Hybopsis kentuckiensis*)
- 10 Creek Chub (*Semotilus atromaculatus*)
- 11 Common Sunfish (*Eupomotis gibbosus*)
- 12 Golden Shiner (*Notemigonus crysoleucas*)
- 13 Log Perch (*Percina caprodes*)
- 14 Yellow Perch (*Perca flavescens*)
- 15 Stone Roller (*Campostoma anomalum*)
- 16 Johnny Darter (*Boleosoma nigrum*)
- 17 Sand Darter (*Ammocrypta pellucida*)
- 18 Black sided Darter (*Hadropterus aspro*)
- 19 Rainbow Darter (*Etheostoma coeruleum*)
- 20 Fan tail Darter (*Etheostoma flabellare*)
- 21 Green sided Darter (*Diplesion blennioides*)
- 22 Storer's Chub (*Hybopsis storerianus*)
- 23 Black nosed Dace (*Rhinichthys atronaso*)
- 24 Common Shiner (*Notropis cornutus*)
- 25 Steel colored minnow (*Notropis whipplei*)
- 26 Blunt nose minnow (*Pimephales notatus*)
- 27 Fat head minnow (*Pimephales promelas*)
- 28 Sucker mouth minnow (*Phenacobius mirabilis*)
- 29 Bullhead minnow (*Chola vigilax*)
- 30 Emerald minnow (*Notropis atherinoides*)
- 31 Straw colored minnow (*Notropis blennius*)
- 32 Shumard's minnow (*Notropis shumardi*)

The bass at Put-in-Bay were never heavily infested. Fifty skin cysts on a 65 mm small-mouth bass was the maximum. The heaviest infestation was in Geauga County. McCormick reported a black-nosed dace (*Rhinichthys atronasus*) 75 mm long with 420 cysts. A 70 mm large-mouth bass from this county had 100 cysts. These two fish were collected August 10, 1922. An 85 mm small-mouth bass collected August 16, 1922, Conneaut Creek, Ashtabula County, had a few skin cysts, and hundreds of these immature trematodes in the intestine and body cavity. The liver of this fish was riddled with large watery cysts of another trematode, *Clinostomum marginatum*.

An 87 mm small-mouth bass from a brook near Tiffin had over 100 skin cysts. Other bass taken from various northern Ohio streams showed this infestation. The infestation was heavier in the minnows.

Crepidostomum cornutum (Osborn) 1903

This trematode was described by Osborn (1903, p. 63-73) as *Bunodera cornula*, but was later placed in the genus *Crepidostomum* Braun, 1900. This trematode was found frequently in the stomach of young and adult individuals of large- and small-mouth bass and rock bass in every locality where these species were examined.

Osborn 1903, described larval cysts of this form in the crayfish and established it as an intermediate host prior to the adult stage of this species in the fish. My work confirmed this in most cases. Cysts with emerging flukes were found in partially digested crayfish taken from the stomach of adult bass. In southern Ohio streams crayfish formed the chief article of diet and this form was abundant.

Young fish obtain this trematode very early. The cysts in this case must be carried by smaller crustaceans. The forms found in the young bass were in the stage of early sexual maturity.

This fluke was easy to stain and gave the best preparations of any of the trematodes studied. This distome was found in the stomach and pyloric caeca of nearly all small-mouth bass examined from the streams of southern Ohio. The numbers of parasites per fish ranged from 4-25. These parasites were often obtained early by the young fish. In a 15 mm small-mouth bass taken June 26, 1922, six immature *C. cornutum*.

were found in the stomach. They averaged 3-10 mm in length. Many others were found in June and July from young bass 17-28 mm in length. In one case an immature fluke of this species was found encysted in the liver of an adult small-mouth bass taken at Put-in-Bay.

Clinostomum marginatum Leidy, 1856

This fluke was first reported in America by Leidy (1856) in the intestine of pike (*Esox lucius*) in the Delaware River and in cysts attached to the gills of the sunfish (*Eupomotis vulgaris*).

Braun (1900) in a revision of the genus recognizes eight species of the genus *Clinostomum*, among them *C. marginatum*. Osborn (1911), (p 350-364), gives many records for the distribution of this form and among the hosts infected reports specimens of this fluke encysted in the muscle tissues of *M. dolomieu*, collected at Nebish, Michigan. He also records its occurrence in *M. dolomieu* taken at Troy, Ohio, from the Miami River. Some of these larval flukes were encysted in muscle and others in the skin on the internal aspect of the branchiostegal membranes. According to Osborn, 1911, these cysts were most abundant the latter part of August and early in September. Osborn (1911, p 354) gives a table showing distribution records. The following additions can be made from my data.

Clinostomum marginatum

Host	Adult	Locality	Number Parasites	Location in Host	Date
<i>M. dolomieu</i>	Adult	Little Miami Lebanon	8	cysts about tail	9-4-22
<i>M. dolomieu</i>	4.2 cm	Sugar Isle Lake Erie	4	stomach cysts from food	7-11-22
<i>M. dolomieu</i>	8.5 cm	Conneaut Creek Ashtabula	many	liver cysts	9-16-22
<i>M. salmoides</i>	30 cm	Newtown Fish Hatchery	4	liver cysts	9-2-22
<i>Eupomotis gibbosus</i>	Adult	Put-in-Bay	many	liver riddled muscle cysts	7-25-22

These forms were all small and usually few in number
They were all sexually immature

Leucercuthrus micropteri Goldberger, 1911

The genus was described by Marshall and Gilbert (1905) and this form described from the black bass of Wisconsin and Indiana by Goldberger ('11) These flukes enter the bass quite early All these flukes were found in the stomach They were usually in larval condition The most unusual occurrence was the finding of two of these adult flukes, one measuring 6.4 mm in length and the other 7.4 mm long, in a 17 mm large-mouth bass examined June 28, 1922 They were sexually mature and had the uterus filled with eggs All others found were larval or in early maturity These forms were more often found in the large-mouth bass than in the small-mouth bass

These flukes were found in small numbers The heaviest infestation occurred in an 11.2 cm large-mouth bass from West Harbor, Lake Erie There were ten in the stomach They measured 2.0–3.5 mm in length These were not usually obtained until the bass attained a length of 35–40 mm

All of these distomes were found in bass obtained from various locations in Lake Erie They were not found in fish taken at the State Hatcheries or from Ohio streams

Azygia Looss, 1899

Many records have been given for species belonging to this genus in *M. salmoides* and *M. dolomieu* as well as for other fish All the flukes found belonging to this genus were in early sexual maturity

Two of these parasites were found in the stomach of a 52 mm small-mouth bass from Put-in-Bay Six large-mouth bass from East Harbor had from 2–6 of these flukes in the stomach

Microphallus opacus Ward, 1901

This form has been reported for *M. dolomieu*, *Amia calva*, *Anguilla chrysypa*, *Ictalurus punctatus*, and *Perca flavescens* As reported by Ward ('94) and Osborn ('02), this form has its earlier stage in crayfish, according to Ward "in the space in the cephalothorax above the heart and sexual organs"—and Osborn says "it is found invariably in the liver (of crayfish) whose effective area is frequently greatly reduced by the cysts "

My only findings for this species were in two large-mouth bass obtained at Paint Creek, Fayette County, Ohio. One specimen 28 cm in length had ten of these parasites in the upper intestine. They measured 50-85 mm in length. The other bass measured 17 cm and had six of these parasites in the upper intestine.

NEMATODE PARASITES

No attempt will be made at this time to describe or identify all the nematode species found in the large- and small-mouth bass. These parasites were never found in large numbers in the bass.

The adult small-mouth bass of southeastern Ohio were most frequently infested with intestinal nematodes. These were the largest forms found in the bass. They probably belonged to the family Ascaridæ. They have a mouth with three rather prominent lips, a smooth body and no spines. The females measure from 30-45 mm and have an abruptly pointed posterior end. The males measure 20-35 mm and have two prominent spiracles of equal size.

In the young small-mouth bass at Put-in-Bay nematodes appeared late in the first season and never in large numbers. The form most often found was *Spinthictus gracilis* (Ward and Magath). Five were found July 17, 1921, in the intestine of a 50 mm small-mouth bass. Other nematodes of this species were found in larger small-mouth bass, but never in large numbers.

No nematodes were found in 1922 until July 15 and then only in about one-third of the young fish examined during the season. In some of the bass many encysted forms were found belonging to the family *Filaridæ*.

The large-mouth bass had likewise few nematode parasites. More encysted *Filaria* were found, these after the bass had reached 30 mm in size.

In the intestine of a 10 cm large-mouth bass from West Harbor, obtained July 12, 1922, two nematodes belonging to the genus *Camallanus* were found. Similar individuals were found in a few other large-mouth bass. In a slide labeled "Young small-mouth nematodes," July 20, 1921, Put-in-Bay, two individuals of this genus were present.

ACANTHOCEPHALA

This group of parasites has been studied for the bass as well as other hosts by Van Cleave ('13 and '19, a and b) Acanthocephala were often found in large numbers attached to the inner wall of the intestinal tract of adult bass. They were more prevalent in small-mouth bass. In younger bass one form, *Echinorhynchus thecatus* Linton, 1891, was often found encysted in the mesentery and pyloric caeca. This species was the one found in largest numbers in adult bass.

E. thecatus and *N. cylindricus*
Measurements in cm

Host	Size	Date	Locality	N. cyl in host	E. the encysted	E. the in int
M. salmoides	3 6	7-15-21	W H			1
" "	13 5	7-15-21	W H			Many
" "	4 9	7-26-21	E H	1		1
" "	15 0	7-26-21	E H	7		2
" " 17 spec	4 5-6 0	8- -21	Akron Hatchery	few	1-10 in viscera	2-25
M. salmoides	3 1	7-12-22	W H	1		
" "	2 9	7-12-22	W H	1	3 pyl caec	
" "	3 5	7-12-22	W H			2
" "	3 6	7-14-22	W H	1		1
" "	3 1	7-19-22	P i B	3	2 mes	
" "	17 0	7-26-22	Akron Hatchery	20		3
" "	17 0	8-8-22	London Hatchery	1		
" "	5 6	8-27-22	P i B		5 mes	
" "	9 5	9-13-22	W H	few int	5 mes 2 pyl caec	
" "	18 5	9-8-22	Fayette Co	many int		

E H—East Harbor
W H—West Harbor
P-i-B—Put-in Bay

Van Cleave '20, studies the life history of *E thecatus* and says regarding this "Larvæ of *E thecatus* have been found in *Hyalella knickerbockeri*. The young bass fed on these amphipods acquire a general infestation of *E thecatus* ". He also says ('20, p 170), after discussing the amphipod as the intermediate host "Data from other sources furnish incontestable evidence that one or more intermediate hosts may be intercalated between the primary and the definitive hosts of *E thecatus* Larvæ which unmistakably belong to this species have been encountered frequently encysted in the viscera of various fishes "

In my studies none of the encysted forms were found until the bass began to eat amphipods. No encysted *E thecatus*

E thecatus and *N cylindricus*
Measurements in cm

Host	Size host	Date	Locality	N cyl	E the	Degree of infestation in E the
M dolomieu	4 0	7 6-21	P B		int	medium
" "	6 0	7-18-21	P B	2		
" "	12 5	7-18-21	P B		int	6
" "	6 4	7-20-21	P B	1	int	1
" "	5 8	7-22-21	P B	3		
25 " "	18-35	9- -21	Clinton and Green Counties	few	int	medium to heavy
" "	10 0	7-4-22	P B	20	int	light
" "	18 5	7-9-22	P B		int	50
" "	23 0	7-15-22	P B		int pyl caeca	heavy 300
" "	3 5	7-19-22	P B	2	int	1
" "	11 0	7-19-22	P B	3		
" "	20-34	7-27-22	P B	few	int pyl caeca	heavy
" "	6 5	8-26-22	P B	4	int	2
" "	15-32	10- -22	Clinton and Green Co	few	int pyl caeca	medium

P. B -- Put-in Bay

were found in the small-mouth bass of Put-in-Bay where there are few amphipods in the diet of the bass

Nearly all adult large- and small-mouth bass examined contained *E. thecatus* in numbers ranging from 1 to more than 200. They were found in about equal numbers in the adult bass from Lake Erie and southern Ohio. They were more abundant in bass examined in the fall.

The other species found in the large- and small-mouth bass was *Neoechinorhynchus cylindricus* Van Cleave, 1913. This species was found from many localities in large- and small-mouth bass, but never in large numbers. They were not found in the encysted stage, but always free in the intestine. The following tables give some idea of the time of infestation in young bass.

PARASITIC COPEPODS

Two species belonging to the family Ergasilidae were found attached to the gills of large- and small-mouth bass in a few cases. There were never more than three or four of these parasites per fish. In all, not more than thirty of these parasites were found in all of the fish examined. The Ergasilidae in North America were studied and new species recorded by Wilson ('11).

One species of Lernaeidae was occasionally found attached to the host. Usually but one specimen was found on a host and but few bass were infested with this form.

DISCUSSION

The parasites which were most injurious to the bass in addition to the cestode parasites, *P. ambloplitis* and *P. fluviatilis*, were, the trematodes which infest the liver, skin and muscles, and those acanthocephala which are found encysted in the mesenteries in immature stages and as adults attached to the intestinal mucosa.

In young bass the most evident damage was done by forms which infest the liver and mesenteries such as was evident in a few cases where *Clinostomum marginatum* were found in large numbers, and by the encysted forms of *E. thecatus*. The size of a badly infested fish as compared with others of the same age, and the amount of fat in the mesenteries were criteria for estimating the damage. The more the retardation in development of the fish, the greater opportunity there is for

this fish to be eaten by bass or other carnivorous forms. In older fish the vitality is often much lowered by parasitism.

A small-mouth bass three years old which died at the Akron Hatchery was examined and found to be very heavily infested with *E thecatus* in mesenteries and adults of the same species in the intestine. The fish was 12 cm in length and weighed but 14 ounces. Several other fish were found in almost the same condition. Some had their gonads destroyed by a larval cestode *P ambloplitis*.

Considerable damage was reported in adult bass taken in northwestern Ohio, due to skin and muscle cysts of *C marginatum* and *C chyli*. In many cases these fish were unfit for food. Too few of these badly infested fish were examined to give data as to the extent of this infestation.

Parasitism seems to be of considerable importance at certain of the inland fish hatcheries. At the Newtown and London hatcheries very few infested fish were found and those that were found were usually the adult fish brought in from some other location. Perhaps the intermediate hosts had not become established. At the Akron hatchery there was marked infestation of both large- and small-mouth bass. In general the infestation of young bass was much heavier than those studied from Lake Erie in the vicinity of Put-in-Bay. More work should be undertaken regarding the importance of parasitism as a limiting factor at the fish hatcheries.

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THE NATURAL VEGETATION OF OHIO

II THE PRAIRIES

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INTRODUCTORY STATEMENT

It is well known that many treeless areas existed in Ohio before white settlement. These areas, of various ecological character and usually restricted in size, were in a few cases fairly extensive—embracing from fifty to one hundred square miles. The term "prairie" was rather generally applied to them, although more exact terms were not wanting. Like the various forest associations, these treeless areas have played an important rôle in influencing industrial and cultural phases of human life in Ohio (1). The present paper is an attempt to reconstruct such areas, now destroyed or obscured by secondary successions induced by white men. In this as in the preceding paper on the virgin forests of Ohio (2) the question of succession has been intentionally postponed.

The sources consulted in this work are essentially those drawn upon for the preceding paper, to wit, field notes of original surveys, county and other local histories, accounts of travelers and pioneers, and occasional papers by the early naturalists who knew this region. Taken together all of these supply a fair system of checks. In many cases also the writer's own field observations have been of service, since isolated remnants are still to be found along roadways and elsewhere.

In addition to the friends whose assistance has been earlier acknowledged, the writer wishes to express his gratitude to Mr. Emory C. Leonard of the U. S. National Herbarium, who kindly consented to check the numerous synonyms in the floristic lists. Thanks are also due to Miss Clara G. Mark for suggestions in relation to physiographic problems.

WORDS USED TO DESIGNATE TREELESS AREAS

As stated above the term "prairie" in the early records meant a treeless area, generally grassy, but sometimes covered with low shrubs or brush. It might be wet or dry. The following terms seem to have been somewhat narrower in their meaning.

Wet Prairie—Equivalent to wet meadow, generally consisting of sedges, rushes, and grasses, e g, *Phragmites* and *Calamagrostis*. It was sometimes extended to include cattail and pickerel weed associations, and not infrequently used to indicate bog meadow, i e, "cranberry prairie."

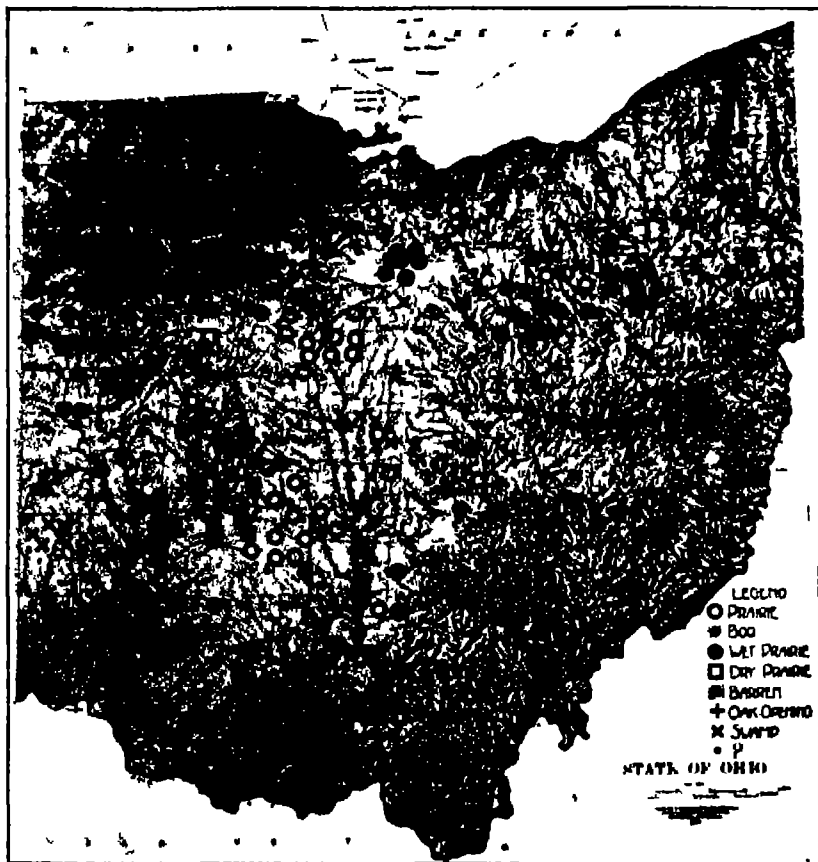


Figure 1

Position of the treeless areas of natural vegetation in Ohio. Based upon records made between 1750 and 1850, and checked in many cases by field observations. Symbols indicate character as designated in early records.

Dry Prairie—One in which no standing water was found, most frequently the marginal zone of a wet prairie if the nearby trees were sparse, in some cases merely the late summer aspect of a normally wet prairie, at times perhaps the more or less direct result of fire.

Bog —Largely in the modern sense, referring to a depression filled or filling with peat, the product of a boreal flora

Swamp —Habitat marked by standing water for most of the year, occupied either by herbs (aquatics such as cattails and pickerel weed, etc), shrubs (small willows, alders, buttonbush, etc) or trees (ash-elm, tamarack-alder, etc)

Swale —Apparently a small swamp

Marsh —An herbaceous swamp, generally an extensive one, also used specifically to designate the bog meadow, e g "cranberry marsh "

Barren —An habitat in which tree growth is scrubby, defective, or even absent, used alike in cases of deficient and excessive soil moisture

Oak Opening —Essentially oak savannah, the oak forming open thin groves, or being present as scattered clumps or individuals, with the (generally lower) ground between occupied by grasses and other herbaceous vegetation

EXPLANATION OF THE MAP

The foregoing glossary is not ideal, but it represents just what we have for our work With the accompanying map, Fig 1 (1922 U S G S relief map of Ohio) will be found a key to the conventional signs used These signs, centered upon the habitat they designate, are a key to position and quality, but not to size of habitat It will be noted that "swale" and "marsh" have not been used, but the remaining terms are used in as near their modern restricted sense as available descriptive records will allow Upon this basis selection has been made between synonyms where possible In certain cases it is not clear whether two terms were intended as synonyms—they may have referred to two adjoining but differing associations or to different seasonal aspects of the same area In these and all other cases of too meagre information the map has entered upon it just what the records say, and with this we must rest content It will be noted that there is a symbol for questionable or uncertain cases which has been freely employed

It should be explained that all of the "swamps" marked in Preble County and several of those in Delaware, as well as the "bog" on the lake shore in Lake County were wooded, and not at all treeless There has been no attempt to map all bogs—chiefly those are shown whose bog-meadow stage earned them at one place or another in the records the name of "prairie "

The bogs of Ohio have, of course, been studied in detail by Dachnowski (3) to whose work the reader is referred

While most of the symbols represent patches of small area there seem to have been no less than five regions in which the prairies were of considerable size in the aggregate. These coincide with areas marked "Oak" in the virgin forest map (2). First, there was the sandy region of Fulton, Lucas and Wood counties, second, the thin-soiled limestone region of Sandusky, Erie, Seneca, and Huron, third, the sandy region of oak openings in Wayne and Stark counties, fourth, the Wyandot and Sandusky Plains of Wyandot, Marion, and Crawford counties, fifth, the Darby Plains of Union, Madison and adjacent counties. If to these we could add the marginal wet meadows along Lake Erie, the grass-covered depressions within the Erie Basin and upon the divide, the chains of "cat-head" prairies in the filled valleys of the two Miamis, the Scioto, and the Licking, the resulting total would at least cover two average counties. Fifteen hundred square miles represents a rough, but conservative estimate of the total natural treeless area in Ohio.

PRAIRIES AND PHYSIOGRAPHY

Comparing the position of the treeless areas as marked in Fig 1 with the physiographic boundaries in Ohio shown in Fig 3 of the preceding paper of this series (2), certain general correlations at once appear. These are, briefly, as follows:

- 1 Treeless areas were practically absent from the unglaciated portion of the state.

- 2 They occurred all along the Ohio-Erie Divide, but in groups rather than at random.

- 3 These groups swung away to the southeast of the Divide in a series of crescent-like extensions.

- 4 North of the Divide the Erie Plain contained a series of curving groups, the innermost being along the present margin of Lake Erie.

From the fact that prairies were found only in the glaciated region one is justified in expecting a relation between glaciation and prairies. The parallel crescentic arrangement of these treeless areas suggests at once a correlation with the system of glacial moraines, (see Fig 2). In most cases radii of these arcs approximate the direction of glacial movement, as can be verified by studying a map of the glacial striæ in Ohio. Like

the accompanying Oak of the virgin forest, then, the prairies in general occupied the regions near the apices of the glacial fronts, where outwash and ponding were the rule. As concrete examples of such habitats may be cited pondings in Mercer and

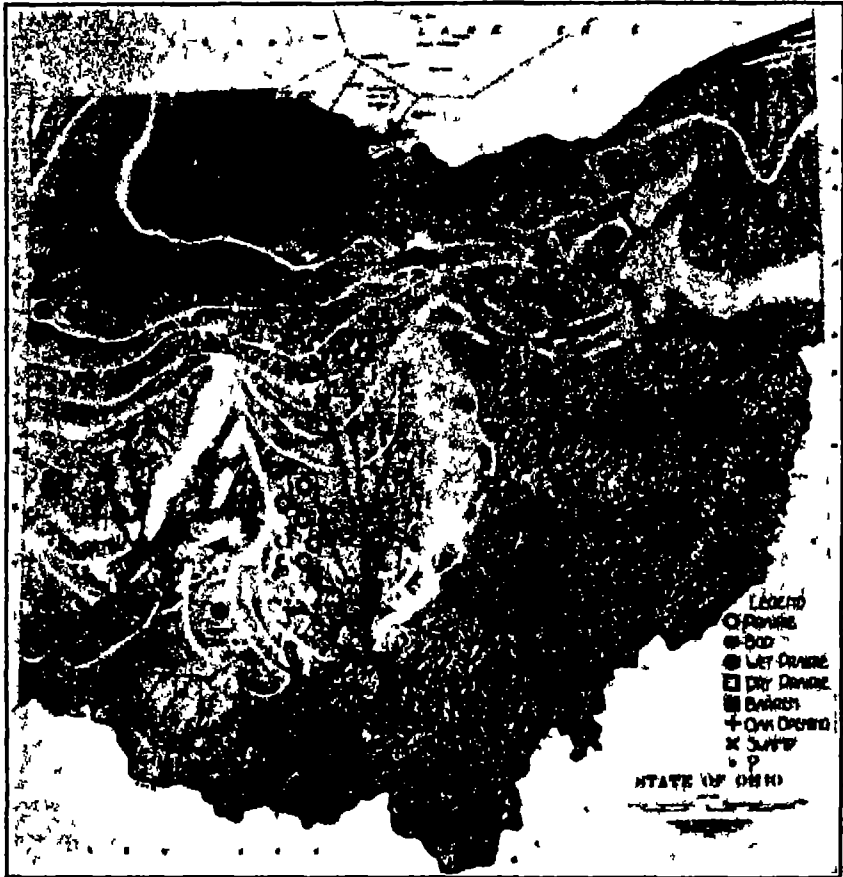


Figure 2

Relation of the natural treeless areas of Ohio to the system of moraines as traced by Leverett in U S G S Monograph 41. Note the correlation with regions of glacial outwash and ponding. Consult Fig 1 for symbols not visible here.

other counties, flats in Marion County, and filled preglacial valleys, whether silted and ponded as along the Miami, or gravel-filled and presumably overdrained, as in Pickaway County. Unlike the Oak the prairies occupied the actual depressions, although in their dryer phase they extended upward

towards and even into the Oak on higher ground. Besides these generally apical positions, prairie was found associated with Oak in the sand dune and pan of Lucas and Fulton counties, and the limestone ridge and shallow basin of Sandusky County.

Apart from the dryer ridges or marginal zones and the coarse gravel beds most of the prairies must at one time have been sites of either definite lakes, or seasonal ponding. There is no reason to doubt that Ohio has metamorphosed through the familiar postglacial stages now found farther north, in Michigan, Minnesota, and Canada. Orton (4) found evidence of a former extensive shallow lake upon the region occupied by the Darby Plains in Union and Madison counties. Numerous soil borings made by the writer upon former prairie sites have shown a layer of blue hardpan, generally close to the surface. Moreover, a large number of these areas are shown by the sheets of the Topographic Survey to possess a fall of considerably less than ten feet to the mile.

SURVEY OF PRAIRIE HABITATS

Within the Erie Plain proper were found four distinct zones or belts of treeless areas, corresponding to the present or 5th beach of Gilbert (5), the 4th, 2nd, and 1st. The 3rd beach was not so well marked in this way, (cf Fig 3).

Two of these curving beaches, the 2nd and 4th, ran into sand hills at their northern end, resulting in oak openings on the dunes and wet meadows in the pans. Bogs were present in the two oldest beach zones but not in the younger ones. At their eastern end the beaches converge somewhat as they approach and cross the bare limestone ridge which runs southward from Sandusky Bay. Upon this ridge were found open groves of scrubby oak, while the shallow soil upon its flanks showed prairies, wet in some cases, as at Castalia, and probably dry in others.

Between the sandy northern and rocky eastern ends the beach lines curve across the broad flat Maumee Valley formerly occupied by Lake Erie—the Black Swamp Region. Here at intervals were prairies, generally wet. In Wood County, (6a), Van Wert, (6b), and Huron counties especially these prairies had the shape of old estuaries or baymouths similar to the present Sandusky Bay, for example.

The Erie Plain corresponds closely to the Erie Basin, save at the eastern end, where the present Ohio-Erie Divide lies some distance south of the escarpment near the lake which separates Erie Plain from Alleghany Plateau Upon the intervening strip



Figure 3

Relation of natural treeless areas of Ohio to preglacial drainage lines and postglacial lakes. Shores of postglacial lakes in Erie Basin shown in white preglacial valleys in wide black (approximations in narrow black). White arrows indicate beach sand, black arrows small postglacial lakes. See text for further explanation.

of plateau prairies were quite lacking. Along the divide, however, prairies abounded, mostly being depressions or inadequately drained flats. These prairies of the divide fell into at least five distinct constellations or groups, each of which curved

away to south and east as already noted. These groups were found in Mercer, Hardin, Wyandot-Marion-Crawford, Ashland-Wayne, Wayne-Stark-Summit, with perhaps a sixth group in Portage-Mahoning and a seventh in Trumbull County. In at least Mercer, Ashland, Stark, and Wayne counties all or many of these wet prairies marked the course of deep, buried and silted preglacial drainage valleys, as is shown by Fig 3. The position of preglacial drainage lines shown by this map is based upon various sources, including work by Read (7), Tight, Bownocker, et al (8), Clark (9), and Tight (10).

Moving southward from the divide there were left four principal regions of prairie—Miami Valley, Miami-Scioto uplands (Darby Plains), Scioto Valley, and Licking Valley. All of these regions coincided at least in part with great preglacial valleys (Fig 3), now silted or gravel-filled. That the Darby Plains represented a shallow postglacial lake site has already been mentioned. A somewhat isolated prairie in northern Clinton County is known to lie in a buried valley.

In brief then, there were prairies within the Erie Plain, along old shore lines and in ancient bays, prairies along the Ohio-Erie Divide, many of which were within buried valleys or the sites of postglacial lakes, and prairies in the glaciated Ohio Basin, of which the same statement may be made. In the face of such correlations, any serious attempt to invoke fire as a prime cause of Ohio prairies must vanish, although fire doubtless played a rôle in their history. That these more detailed correlations are not inconsistent with the general morainal relations pointed out earlier, a little reflection will show. The major outlines of glaciation were fundamentally affected by preglacial topography, as were the details of outwash channels, etc. This point, made clear for Ohio by Read (7) and others is reiterated because of the frequency with which explanations involving "accidental" pondings and other topographic features were encountered early in this study. *There have been no accidents.* In fact, so striking is the relation between preglacial topography and natural vegetation that the writer does not hesitate to express his belief that a great preglacial valley will probably be found running northward through Champaign, Logan, Hardin and Hancock counties and another northwestward through Marion and Wyandot counties.

GENERAL APPEARANCE OF THE ORIGINAL PRAIRIES

A portrait of the prairies is to be found in Cincinnatus (11) Evidently a composite account, it applies well to Ohio conditions Grasses, including *Andropogon furcatus*, *Spartina*, *Eragrostis*, were said not to be turf formers Flowers were abundant, but represented a profusion of individuals rather than species Early aspects showed numerous legumes, *Baptisia*, *Desmodium*, *Psoralea*, *Dalea*, *Petalostemon*—some Rosaceæ, e g, *Rosa*, and *Spiraea*, while from July to October Compositæ outnumbered all other orders During this aspect *Achnomeris*, *Coreopsis*, *Helianthus*, *Rudbeckia*, *Lepachys*, *Echinacea*, *Liatris*, *Silphium*, etc, were conspicuous Under conditions of settlement *Phleum*, *Agrostis*, and *Poa* were rapidly replacing all native plants

From among numerous non-technical accounts which are available a few have been selected below for the graphic impression they give of the undisturbed treeless areas

Christopher Gist, exploring southeast Ohio in 1751 (12) reported it full of beautiful natural meadows covered with wild rye, blue grass and clover (!), abounding with turkeys, deer, elk, and especially buffalo This was in January and February In March, travelling along the Little Miami, he noted that the river continued to run through the middle of a fine meadow about a mile wide, "very clear like an old field and not a bush in it "

Pease, surveying the 6th meridian (13) in 1796, between what is now Geauga and Trumbull Counties, came "to an interval with grass, scattering trees, etc * * * on this interval is elm, white oak, ash, white thorn, elder, the white and red meadow plumb trees full of fruit (Sept 6), which is ripe and excellent of the kind * * * the grass here would make tolerable hay and is generally a good burthen * * * bottom (of adjacent stream) hard clay and gravel "

Mr C E Custis, describing to the writer the prairie in northern Clinton County, said that his mother came there in 1803 and in riding to school she often found the grass as high as her horse and head There were some scattering clumps of trees Cattle frequently mired in the "lower" prairie In 1869, when Mr Custis bought his present place, the "upper" prairie had been slightly drained and was covered with wild rose bushes, grasses, and some wild plums

Cyrus P Bradley (14) travelling through Ohio in 1835, says concerning the Pickaway Plains, "Our farmer described with great enthusiasm the appearance of these plains when he first pitched his tent upon its border. A natural plain of from three to seven miles in extent, covered with a low wild plum producing a luscious fruit, and without a single tree in its whole extent to obstruct the view." Trees were later introduced. If one visits Pickaway Plains today and examines the walls of cellars and other excavations he learns that the whole is underlain by many feet of pure, coarse gravel.

The same traveller, proceeding from Marion to Sandusky, says "Our road lay through low prairies and wet of course. * * * Prairie land is not necessarily wet or low. * * * But the prairies we passed over today are what we might call meadows, very low and wet, incapable of being drained, in a state of nature, unsusceptible of improvement. They are used for grazing and are exceedingly profitable. * * * In one instance we turned from the road and waded through the long grass of the prairie for miles, preferring a foot of unadulterated water, for it stood to that depth on the surface of the ground, to as great or greater depth of mud. * * * I shall never forget my ride across those gloomy unhealthy prairies which produce nothing but long grass, horned cattle, disease, mosquitoes, and rattlesnakes. One species of meadow grass was shown to me which is given the singular cognomen of Roman Catholic Grass. * Why, I did not learn."

The historian of Madison County (15) records that it is "well authenticated that a great portion of Madison County was originally covered with water most of the year. The first settlers called these lands barrens and looked upon them as utterly unfit for farming purposes. * * * The prairies consisted of level stretches of country covered with sedge-grass, and dotted here and there with patches of scrubby burr-oak growing upon the highest points of land. The sedge-grass grew to an enormous height, sometimes sufficient to hide man and horse when travelling through it, but [was] very nutritious for stock. * * * Nearly every autumn prairie fires swept over the country, destroying everything in their path. * * * But * * * these fires grew less frequent. * * * Timber on the east bank of the streams was always

* *Heterochloa odorata* is native to Ohio, but is not listed by Schaffner (17) for the counties between Marion and Sandusky.

the largest, as these fires generally ran from west to east * * * The growth of the burr-oak on the prairies was impeded by these periodical fires, and the greater amount of the present timber * * * has grown up since " The same authority quotes at length from an early physician, Doctor Converse In vivid if empirical description is emphasized the extent and variegated color of the prairies Three species of grass seem to have been dominant, one doubtless *Phragmites*, on the lower portions, two apparently including *Andropogon* on the upper Numerous dicots are mentioned, notably *Silphium terebinthinaceum*, *Helianthus* sp., also *Iris*, *Lilium*, etc

To Mr Ephraim Monnette, born about 1835 on the Sandusky Plains between Bucyrus and Marion, the writer is indebted for a keen and intelligent verbal description of this region At Tobias, toward the center of the area was a "Big Spring" of about one acre, covered by a floating sod of "moss," under which were fish and in which cattle were often mired This was a dependable source of water the year round, even in very dry times Just what this "moss" was would be a very interesting thing to know, but there is now no way of learning To the writer's knowledge there were a number of other ponds, spring-fed, in this district

Higher than the ponds, but still very wet, were the "prairies" proper Their chief grass was quite tall, grew in tussocks, and possessed a "frizzly" head, on top of a hollow jointed stem This was certainly *Phragmites* Duckweeds were also described unmistakably, while *Lobelia*, quaking asps, slippery elm and "p— elm" were designated by name

The so-called "plains" were dryer than the preceding They bore strawberries in profusion, thorns, wild plum, puccoon root (white and yellow), wild turnips, indigo, rosin weed, sunflower, etc The coneflower (*Rudbeckia*) made its appearance wherever the hogs rooted In these dryer "plains" a shorter grass, described as having a defective or concealed head (possibly *Andropogon scoparius*) was dominant

Upon the higher ridges or "islands" were oak, especially jack oak and hickory, also thorn, grape, hazel, (wild roses) and wild plums everywhere

In early days these Sandusky Plains were drained by the Scioto, which was uncertain and feebly marked Since lowering of the water table by drainage the stream has been growing and its channel deepening Where the prairies have been disturbed,

blue grass has supplanted the original grasses. This phenomenon has been observed many times before and since.

If one today wished to see the conditions indicated in the preceding descriptions it would be almost impossible to find the fringing shrub zone of plum, rose, thorn, grape and hazel within Ohio, at least in its typical form. Very characteristic wet prairies can still be observed between Fremont and Port Clinton at the western end of Sandusky Bay, but the lowering of the water table has practically obliterated them inland. Drainage has not reacted so unfavorably upon the dryer phase, of which numerous examples can still be found in unbroken roadside sod throughout the former prairie regions of the state.

FLORISTICS OF THE ORIGINAL PRAIRIES

In a publication now somewhat difficult to obtain (16) Riddell gives an extensive list of Ohio and other "western" plants, often specifying habitat and distribution—as they were known in 1835. Although settlement had progressed steadily at that date it is certain that many important prairie areas were still largely in their original condition. Riddell's list then is perhaps our best key to the floristics of the early prairies, but considerable scrutiny has been required to make it usable. All plants not definitely stated to be found in Ohio have been omitted, which accounts for the absence of *Andropogon furcatus*, *Calamagrostis* and a few other important forms which we know were present in great numbers. Plants from each type of treeless habitat have been grouped alphabetically. As far as possible all names have been conservatively modernized, where this has involved a change the old name used by Riddell will be found in parenthesis. In some cases where Riddell gave no authority the presumptive authority has been added. The numbers are his serial numbers, while asterisks mark those plants not listed in Schaffner's Catalog of Ohio Plants (16) or its supplements.

Plants of Ohio Barrens after Riddell 1835

- 967 *Brauneria purpurea* (DC.) Britt. (*Rudbeckia purpurea* Willd.)
- 1078 *Cornus paniculata* L'Herit.
- 466 *Corylus americana* Walt.
- 1216 *Gerardia pedicularia* L.
- 738* *Ilex lanceolata* (Pursh) Chapm. (*Prinos lanceolatus* Pursh)
- 842* *Liatris gracilis* Pursh
- 460* *Quercus ilicifolia* Wang. (*Q. bannisteri* Michx.)
- 459 *Q. prinoides* Willd. (*Q. chinquapin*)
- 448 *Q. stellata* Wang. (*Q. obtusiloba*)
- 461 *Q. triloba* Michx.
- 364 *Tephrosia virginiana* (L.) Pers. (*Galega virginiana*)

Plants of Ohio Bogs, after Riddell, 1835

- 1436 *Cypripedium hirsutum* Mill (C spectabile Swartz)
 1675* *Eleocharis capitata* (L) R Br (*Scirpus capitatus* L)
 1684* *E simplex* (Ell) A Diet (*Scirpus simplex* Ell)
 1445 *Juncus acuminatus* Michx
 770 *Lobelia puberula* Michx
 769 *L siphilitica* L
 1692 *Rhynchospora alba* (L) Vahl
 1693 *R glomerata* (L) Vahl
 617 *Sarracenia purpurea* L
 757 *Vaccinium macrocarpon* Ait (*Oxycoccus macrocarpus* Pursh)

Plants of Ohio Dry Prairies, after Riddell, 1835

- 1462 *Allium cernuum* Roth
 1649 *Andropogon scoparius* Michx
 21 *Angelica atropurpurea* L (A. triquinata)
 23* *A lucida* L
 1105 *Apocynum cannabinum pubescens* (R Br) DC (A pubescens Brown)
 1094 *Asclepias tuberosa* L
 1092 *A verticillata* L
 870 *Aster laevis* L (A cyaneus Pursh)
 860 *A linariifolius* L
 886 (A miser L)
 869 *A novae-angliae* L
 880 *A puniceus* L
 321* *Baptisia alba* (L) R Br
 967 *Brauneria purpurea* (DC) Britt (*Rudbeckia purpurea* Willd)
 941 *Cacalia atriplicifolia* L
 417 *Cassia chamaecrista* L
 536 *Ceanothus americanus* L
 827 *Cirsium discolor* (Muhl) Spreng (*Carduus discolor* Nutt)
 826 *C muticum* Michx (*Carduus glutinosus* Bk)
 20* *Coelopleurum actaeifolium* (Michx) Coult & Rose (*Ligusticum actaeifolium*)
 1128 *Convolvulus sepium* L
 75 *Delphinium exaltatum* Ait
 349* *Desmodium laevigatum* (Nutt) DC (*Hedysarum laevigatum*)
 361 *D obtusum* (Muhl) DC (H obtusum)
 362* *D strictum* (Pursh) DC (H strictum)
 1253* *Dyschoriste oblongifolia* (Michx) Ktze (*Ruellia oblongifolia* Michx)
 508 *Euphorbia corollata* L
 210 *Gaura biennis* L
 211* *G parviflora* Dougl (G mollis)
 1218 *Gerardia tenuifolia* Vahl
 963 *Helianthus giganteus* L
 960* *H scaberrimus* Ell
 965 *H strumosus* L
 967 *H trachelifolius* Mill
 1113 *Houstonia longifolia* Gärtn
 165 *Hypericum proflificum* L
 1130* *Ipomoea macrorrhizus* Michx (*Convolvulus macrorrhizus* Michx)
 937 *Kuhnia eupatorioides* L (K crinita L)
 972 *Lepachys pinnata* (Vent) T & G (*Rudbeckia pinnata* Michx)
 344* *Lespedeza angustifolia* (Pursh) Ell
 340 *L capitata* Michx
 345 *L hirta* (L) Hornem (L polystachia)
 341 *L violacea* (L) Pers
 346 *L violacea* (L) Pers (L divergens)
 838 *Liatris spicata* (L) Willd
 839 *L squarrosa* Willd
 772 *Lobelia spicata* Lam (L claytoniana Michx)
 223 *Oenothera fruticosa* L

- 802 *Prenanthes altissima* L (*P ovata* Ridd)
 795 *P aspera* Michx (*P illinoensis* Pers)
 796 *P racemosa* Michx
 566 *Ptelea trifoliata* L
 1284 *Pycnanthemum virginianum* (L) Durand & Jackson (*P lanceolatum* Pursh)
 970 *Rudbeckia fulgida* Ait
 968 *R hirta* L
 969 *R triloba* L
 1011 *Silphium laciniatum* L
 1010 *S laciniatum* L (*S gummiferum* Ell)
 1009 *S terebinthinaceum* L
 1012 *S terebinthinaceum pinnatifidum* (Ell) Gray (*S pinnatifidum* Ell)
 1006 *S trifoliatum* L (*S ternatum* L)
 919 *Solidago rigida* L
 918 *S tenuifolia* Pursh
 1651 *Sorghastrum nutans* (L) Nash (*Andropogon nutans* L)
 1398 *Tradescantia virginica* L
 1629 *Tridens flavus* (L) Hitchc (*Tricuspis seslerioides* Torr)
 1061 *Triosteum perfoliatum* L
 985 *Verbesina helianthoides* Michx (*Actinomeris helianthoides* Eat)
 1068 *Viburnum pubescens* (Ait) Pursh.

Plants of Ohio Marshes, after Riddell, 1835

- 1390 *Alisma plantago-aquatica* L
 1738 *Aspidium thelypteris* (L) Sw
 1000 *Bidens laevis* (L) BSP (*B chrysanthemoides* Ell)
 68 *Caltha palustris* L
 106 *Cardamine hirsuta* L (*C virginica*)
 11 *Cicuta bulbifera* L
 10 *C maculata* L
 1127 *Convolvulus sepium pubescens* (Gray) Fernald (*C repens* L)
 1436 *Cypripedium hirsutum* Mill (*C spectabile* Swartz)
 241 *Decodon verticillatus* (L) Ell
 1161 *Dodecatheon meadia* L (*D integrifolium* Michx)
 1672 *Dulichium arundinaceum* (L) Britt (*D spathaceum* Pers)
 1677 *Eleocharis intermedia* (Muhl) Schultes (*Scirpus intermedius* Muhl)
 1674 *E palustris* (L) R & S (*S palustris* L)
 1678 *E tenuis* (Willd) Schultes (*S tenuis* Willd)
 1728 *Equisetum fluviatile* L (*E limosum* L)
 930 *Eupatorium perfoliatum* L
 1044 *Galium tinctorium* L (*G obtusum* Big)
 855 *Gnaphalium uliginosum* L
 734 *Ilex verticillata* (L) Gray (*Prinos verticillatus* L)
 1444* *Juncus polycephalus* Michx
 1658 *Leersia oryzoides* (L) Sw
 770 *Lobelia puberula* Michx
 226 *Ludwigia alternifolia* L
 1448 *Melanthium virginicum* L
 1273 *Mentha piperita* L (naturalized?)
 98* *Nasturtium amphibium* Brown
 14 *Oxypolis rigidior* (L) Coult & Rose (*Archemora rigida* DC)
 1223 *Pedicularis lanceolata* Michx (*P pallida* Pursh)
 1140 *Phlox maculata* L
 703 *Polygonum amphibium* L
 699 *P hydropiperoides* Michx (*P mite* Pers)
 97 *Radicula palustris* (L) Moench (*Nasturtium palustre* DC)
 56 *Ranunculus abortivus* L
 63 *R delphinifolius* Torr (*R lucustris* Bk)
 971 *Rudbeckia laciniata* L
 724 *Rumex verticillatus* L
 1663 *Rynchospora glomerata* (L) Vahl
 1391 *Sagittaria latifolia* Willd (*S sagittifolia* Willd)

- 1392 *S. latifolia obtusa* (Muhl.) Robinson (*S. obtusa* Willd.)
 729 *Saururus cernuus* L.
 183 *Saxifraga pennsylvanica* L.
 1679 *Scirpus validus* Vahl (*S. lacustris* L.)
 950 *Senecio aureus gracilis* (Pursh) Britt (*S. gracilis* Pursh)
 12 *Sium cicutifolium* Schrank (*Sium latifolium*)
 638* *Stellaria longipes* Goldie (*S. palustris* Retz.)
 1511 *Typha angustifolia* L.
 1510 *T. latifolia* L.
 1185 *Veronica anagallis aquatica* L.
 1186 *V. scutellata* L.
 1400* *Xyris caroliniana* Walt.

Plants of Ohio "Prairies" after Riddell 1835

- 669* *Achillea millefolium* Michx. (*Amaranthus altissimus* Ridd.)
 670* *Amaranthus miamiensis* Ridd.
 397 *Amphicarpa monoica* (L.) Ell. (*A. comosa*)
 988 *Coreopsis tripteris* Willd.
 520 *Euphorbia dentata* Michx. (*E. hibernica* Ridd.)
 1108 *Gentiana villosa* L. (*G. ochroleuca* Willd.)
 1220 *Gerardia auriculata* Michx.
 275 *Geum canadense* Jacq. (*G. album*)
 1426 *Habenaria psychodes* (L.) Sw. (*H. fissa* Brown)
 615* *Hudsonia ericoides* L.
 1134 *Ipomoea lacunosa* L. (*Convolvulus micranthus* Ridd.)
 1349 *Onosmodium hispidissimum* McK. (*O. hispidum* Michx.)
 1313 *Physostegia virginiana* Benth. (*Dracopis virginianum* L.)
 319 *Prunus americana* Marsh.
 1285 *Pycnanthemum flexuosum* (Walt.) BSP. (*P. limfolium* Pursh.)
 296 *Rosa setigera* Michx. (*R. rubifolia*)
 625 *Silene regia* Sims.
 1008 *Silphium perfoliatum* L.
 1006 *S. trifoliatum* L. (*S. ternatum* L.)
 921 *Solidago riddellii* Frank.
 912* *S. stricta* Ait.
 1169 *Steironema lanceolatum hybridum* (Michx.) Gray. (*Lysimachia hybrida* Michx.)
 1453* *Stenanthium gramineum* (Ker.) Kunth. (*Veratrum angustifolium* Pursh.)
 102 *Strophostyles helvola* (L.) Britt. (*S. diversifolia*)
 1065 *Viburnum prunifolium* L.

Plants of Ohio Swamps after Riddell 1835

- 1520 *Acorus calamus* L.
 989 *Bidens trichosperma* (Michx.) Britt. (*Coreopsis trichosperma* Michx.)
 1417 *Calopogon pulchellus* (Sw.) R. Br.
 1711 *Carex folliculata* L.
 1724 *C. riparia* Curt. (*C. lacustris* Willd.)
 1127 *Convolvulus sepium pubescens* (Gray) Fernald. (*C. repens* L.)
 1678 *Eleocharis tenuis* (Willd.) Schultes. (*Scirpus tenuis* Willd.)
 1600 *Glyceria canadensis* (Michx.) Trin. (*Poa canadensis* Torr.)
 1599* *G. obtusa* (Muhl.) Trin. (*Poa obtusa* Muhl.)
 1193* *Gratiola aurea* Muhl.
 1440 *Juncus nodosus* L.
 1439* *J. setaceus* Rostk.
 1389 *Larix laricina* (DuRoi) Koch. (*Pinus pendula* Ait.)
 1171 *Lysimachia thyrsiflora* L. (*L. capitata* Pursh.)
 1537 *Muhlenbergia mexicana* (L.) Trin. (*Agrostis lateriflora* Michx.)
 580* *Polygala brevifolia* Nutt.
 562 *Rhus vernix* L.
 971 *Rudbeckia laciniata* L.
 1692 *Rhynchospora alba* (L.) Vahl.

- 1698 *Scurpus lineatus* Michx (*Tricophorum lineatum* Pers)
 755 *Vaccinium corymbosum* L
 602 *Viola striata* Ait (*V ochroleuca* Schw)

Plants of Ohio Wet Prairies, after Riddell 1835

- 856 *Antennaria plantaginifolia* (L) Richards (*Gnaphaleum plantagineum* L)
 1090 *Asclepias incarnata* L
 1089 *A. incarnata* L (*A. amoena* Willd)
 1093* *A. michauxii* Dcne (*A. angustifolia* Ell)
 1738 *Aspidium thelypteris* (L) Sw
 869 *Aster novae-angliae* L
 880 *A. punicus* L
 1000 *Bidens laevis* (L) BSP (*B. chrysanthemoides* Ell)
 989 *B. trichosperma* (Michx) Britt (*Coreopsis trichosperma* Michx)
 432 *Boehmeria cylindrica* (L) Sw
 1617 *Bromus purgans* L
 940 *Calalia suaveolens* L
 1417 *Calopogon pulchellus* (Sw) R Br
 767 *Campanula aparinoides* Pursh
 1709 *Carex lurida* Wahl (*C. tentaculata* Muhl)
 1054 *Cephalanthus occidentalis* L
 1203 *Chelone glabra* L
 826 *Cirsium muticum* Michx (*Carduus glutinosus* Bk)
 1078 *Cornus paniculata* L'Herit
 209 *Epilobium densum* Raf (*E. lineare*)
 208* *E. palustre* L
 8 *Eryngium aquaticum* L
 930 *Eupatorium perfoliatum* L
 297 *Filipendula rubra* (Hill) Robinson (*Spiraea lobata*)
 1044 *Galium tinctorium* L (*G. obtusum* Big)
 1110 *Gentiana crinita* Froel (*G. crinata* Willd)
 1107 *Gentiana saponaria* L
 1217 *Gerardia purpurea* L
 1199 *Gratiola virginiana* L (*G. virginica* L)
 1425 *Habenaria fimbriata* (Ait) R Br
 170 *Hypericum parviflorum* Willd
 736* *Ilex lanceolatus* (Pursh) Chapm (*Prinos lanceolatus* Pursh)
 407 *Lathyrus venosus* Muhl
 1658 *Leersia oryzoides* (L) Sw
 1502 *Lilium canadense* L
 773 *Lobelia kalmii* L
 769 *L. siphilitica* L
 772 *L. spicata* Lam (*L. claytoniana* Michx)
 1448 *Melanthium virginicum* L
 1197 *Mimulus alatus* Ait
 1537 *Muhlenbergia mexicana* (L) Trin (*Agrostis lateriflora* Michx)
 1736 *Onoclea sensibilis* L
 14 *Oxypolis rigidior* (L) Coult & Rose (*Archemora rigida* DC)
 193 *Parnassia caroliniana* Michx (*P. americana*)
 1223 *Pedicularis lanceolata* Michx (*P. pallida* Pursh)
 1517 *Peltandra virginica* (L) Kunth (*Lecontia virginica* Cooper)
 1140 *Phlox maculata* L
 1314 *Physostegia virginiana* (L) Benth (*Dracocephalum variegatum* Vent)
 1595 *Poa trivialis* L (naturalised?)
 707 *Polygonum sagittatum* L
 493 *Populus heterophylla* L
 261 *Potentilla fruticosa* L
 796 *Prenanthes racemosa* Michx
 55 *Ranunculus pennsylvanicus* L
 1302 *Sagittaria latifolia obtusa* (Muhl) Robinson (*S. obtusa* Willd)
 481* *Salix discolor* Muhl (*S. coniferae*)
 480 *Salix petiolaris* Smith (*S. rosmarinifolia*)

- 256 *Sanguisorba canadensis* L
 1331 *Scutellaria lateriflora* L
 950 *Senecio aureus gracilis* (Pursh) Britt (S *gracilis* Pursh)
 920 *Solidago ohioensis* Ridd
 1651 *Sorghastrum nutans* (L.) Nash (Andropogon *nutans* L.)
 1645 *Spartina michauxiana* Hitchc (S *cynosuroides* Willd.)
 292* *Spiraea salicifolia* L
 1413 *Spiranthes praecox* (Walt.) Wats & Coult (S *tortilis* Rich.)
 1167 *Steironema quadriflorum* (Sims) Hitchc (*Lysimachia revoluta* Nutt.)
 1168 S *quadrifolia* L (L *quadrifolia* Sims)
 47* *Thalictrum corynellum* DC (T *cornuti*)
 834 *Vernonia fasciculata* Michx (V *corymbosa* Schw.)
 1186 *Veronica scutellata* L
 591 *Viola affinis* Le Conte
 1400* *Xyris caroliniana* Walt
 1655* *Zizaniopsis miliacea* (Michx.) Doll & Asch (*Zizania miliacea* Michx.)

The present known distribution within Ohio of every species in each list has been studied. Those marked with an asterisk are of course not at present recorded as found in the state. Of the remainder, a number are of general distribution within Ohio. Of those whose distribution is restricted, however, practically all are limited to those counties which are shown in Fig 1 of this paper to have contained treeless areas of one sort or another.

No discussion of prairies in North America can be completed without mention of the thorough annotated bibliography of Shimek (18). To the papers cited there the reader is referred for many interesting accounts of the early grasslands. Moreover, in them may be followed the development of theory regarding the ecological significance of grasslands.

It has become somewhat common to speak patronizingly of early attempts to formulate an adequate theory. This is unjust. The first attempts, it must be remembered, preceded our knowledge of glacial physiography, meteorological data on a wide scale, rapid transit, photography, scientific plant geography, and physiology of water relations. One by one, as the current state of knowledge permitted, the locally limiting factors responsible for the absence of trees were perceived by the early naturalists until the whole formed a consistent unit. The broad outlines of this resultant conception have not been seriously modified by modern technical studies. Bourne's wise appraisal of the situation in Ohio, written in 1819 (19) and the judicious summary by Newberry in 1873 (20) deserve to be remembered.

SUMMARY AND CONCLUSIONS

1 The foregoing paper attempts to locate and characterize all of the so-called "prairies" of Ohio which were a part of the native vegetation and of which any record has been found. These areas appear as prairies, wet prairies, dry prairies, bogs, oak openings, barrens, and swamps, all more or less associated.

2 These regions relate themselves obviously to physiography. In general they represent areas of inadequate drainage or actual ponding consequent upon glacial outwash near the apices of the various morainal lobes. Within the Erie Basin they mark the ancient shore lines. There seems to be a sufficiently close relation between preglacial topography and the position of the glacial moraines to bring a large proportion of the prairies within the silted valleys of preglacial drainage lines.

3 By use of nontechnical contemporary descriptions an attempt is made to reconstruct the physiognomy of the original prairies. Apart from bog meadows most of them were wet, displaying variously *Juncus*, *Scirpus*, *Typha*, *Phragmites*, *Spartina*, *Calamagrostis* and *Andropogon furcatus*, as well as numerous dicotyledonous herbs. Sometimes elm, ash, willow were conspicuous invaders. In other cases there was a dryer herbaceous border dominated by *Andropogon scoparius* with various composites, etc. Between this and the oak-covered uplands was frequently a shrub zone of plum, hazel, and wild rose. Still higher were open groves of oak and hickory.

4 A floristic reconstruction of the various types of prairie has been made upon the basis of Riddell's Early Western Flora.

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NOTES ON THE DEVELOPMENT OF THE GAMETOPHYTE AND EMBRYO OF ASPLENIUM ANGUSTIFOLIUM MICHX

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OCCURRENCE

Asplenium angustifolium Michx, (*Asplenium pycnocarpon* Spreng), the Narrow-Leaved Spleenwort, may be found from western Quebec and New Hampshire to Minnesota, and southwards to Georgia, Alabama, Missouri and Kansas (Gray, 24, and Britton and Brown, 6) Eaton (12) states that it probably occurs in the mountains of northern Georgia, and that it is more common in the Ohio valley than in New England He also states that it has no close relatives anywhere, the nearest being a South African species, *Asplenium anisophyllum*

There are two records of its occurrence in Louisiana, (Pennell, 21), and it is listed in Mohr's "Plant Life of Alabama," from a mountain region with an elevation of fifteen hundred feet The Louisiana station is at an elevation of less than two hundred feet Otherwise its southern distribution seems to be montane

Asplenium angustifolium is reported as occurring very abundantly in some places in Camden County, Missouri, especially in limestone sinks, where it may cover an acre or more, to the exclusion of other vegetation (Standley, 26) It is generally spoken of as one of the rarer ferns by New England students of the pteridophytes, but when found, is frequently reported as growing closely associated with Goldie's Fern, *A Goldianum* (5, 11, 16)

Of interest in connection with the occurrence of *A angustifolium* is the following note by A H Young (41) from the first issue of the Botanical Gazette, then called the Botanical Bulletin, published in November, 1875

"*A angustifolium* * * * is found in southern Indiana It is an inhabitant of cooler regions, and here it seeks the coolest and dampest portions of the ravines running back from the Ohio river, and it is always found encircled by a rich carpet of moss to shield its roots from the heat and retain sufficient

moisture It is by no means abundant, and indeed this remark will apply to all our ferns with the exception of three or four species "

A survey of Ohio botanical literature indicates that the Narrow-Leaved Spleenwort is not a common plant There are specimens in the herbarium at the Ohio State University from twenty counties, not including Delaware County Griggs (18) includes it in his list of plants of the Sugar Grove region Moseley (19) speaks of it as infrequent in Erie County Schaffner (25) lists it as general, but not common in the state

The single plant from which spores for this work were obtained, was found in a shaded ravine on the east side of the Scioto River Valley, about four miles west of Delaware, Ohio

A. angustifolium is usually found in ravines in rich soil, where shade and moisture are abundant One writer (33) states that it prefers a basic soil, but tests of the soil around the plant used in this work showed results to the contrary

The stipes grow in tufts, are very erect, and are from one to four feet in length The leaves are pinnate, with numerous pinnæ, which are linear-lanceolate, acuminate, with entire margins The fertile fronds are narrower than the sterile The fruit dots are linear The fronds are very thin and are easily affected by frost Woolson, as quoted by Tilton (32), writes of it, "There is nothing in the fern kingdom which looks so cool and refreshing on a hot day as a mass of this clear-cut, delicately made-up fern "

WORK ON RELATED GENERA

So far as the writer has been able to discover, no work has been done on the gametophyte of *A. angustifolium*, and except for the work of Campbell (9) and Pickett (23), very little has been done on the complete development of the gametophyte of any of the Polypodiaceæ The former has described the development of *Onoclea Struthiopteris*, and the latter more recently has worked out the development of the prothallium of *Camplosorus rhizophyllus*

Much has been done, however, in the study of certain phases of the development of the gametophyte of the Polypodiaceæ Atkinson (2) was the first worker to report polyembryony in the ferns He found this condition in *Adiantum cuneatum* Recently Etter (13) has successfully determined

methods for bringing about polyembryony in *Matteucia Struthiopteris*, *Dryopteris mollis*, *Onoclea sensibilis*, and *Pteris longifolia*

Farlow's (14) discovery of an asexually developed sporophyte on *Pteris cretica* var *alba lineata* in 1874, was the beginning of numerous studies in apogamy* Steil (27) has described apogamy in *Pellea atropurpurea*, and (28) in *Notholaena*, *Pteris* and *Aspidium* Miss Wuist (38, 8) had similar results with *Phegopteris polypodioides* and *Camptosorus rhizophyllus* Yamanouchi (39, 40) has done a very excellent piece of work on *Nephrodium*, in the study of apogamy, spermatogenesis, oogenesis and fertilization

Miss Ferguson (15), without knowing of Miss Black's (3) work on imbedded sexual cells in *Dryopteris stipularis* and *Nephrodium molle*, found similar structures in some species of *Pteris* Miss Black's paper, which was published first, raises some very interesting questions as to sex inheritance, and the influence of environmental factors, particularly direct sunlight and dryness, on determination of sex She also raises some question as to the validity of Yamanouchi's assumption that the embryo shown in Plate 10, Figure 29, (40) developed in an apogamous manner from the shaded cell in his Figure 1

Goebel (17)* has given an account of apospory in *Asplenium bulbiferum*, and Steil (29, 30) has reported this condition in *Pteris sulcata* and *Polypodium irioides*

Miss Wuist (35, 36) and Mottier (20) have studied the environmental factors controlling sex in the prothallia of *Onoclea Struthiopteris* A reference is made to their work later

Miss Black (4) has reported branched cells in the prothallia of *Onoclea sensibilis*, and Miss Wuist (37) records many genera and species of the Polypodiaceæ in which branched prothallia occur The branched cells reported by Miss Black were developed under water A deficient oxygen supply was believed to be the cause of this abnormality Miss Wuist's results were attributed to nutrition

Several other unrelated papers have been published, bearing on some phase of the development of the gametophyte of the Polypodiaceæ Some interesting observations on unequal segmentation in the embryo of *Adiantum cuneatum* and *Pteris serrulata* have been made by Atkinson (1) Woodburn (34) found an instance of polyspermy in *Onoclea Struthiopteris*

*The writer was unable to secure the original papers

Four neck canal cells with a definite wall between two of the neck canal cell nuclei, were found by Miss Pfeiffer (22) in *Pteris longifolia*. Successful attempts at regeneration from young detached sporophyte leaves of *Phegopteris polypodioides* were made by Mrs. Brown (7). The leaves were placed in sand moistened with nutrient solutions. One produced a prothallus-like structure which in turn produced four new sporophyte leaves. Vegetative reproduction, and development of prothallia and secondary antheridia from both antheridia and archegonia, have been observed by Steil (30, 31) in *Polypodium irioides*. He assigns unusual cultural conditions as the cause.

THE SPORE AND ITS GERMINATION

Before germination the spores are enclosed in a roughly and irregularly wrinkled perinium (Text-Fig 1, A). They are spherical and are about 50 micra in diameter. Germination begins with the swelling of the endospore and rupturing of the perinium, followed by the extension of the first rhizoid, which makes rapid growth (Text-Fig 1, A, B, C). Chloroplasts are numerous in the swollen endospore, though not so densely crowded together as in older cells. The chloroplasts are oval in shape. The perinium adheres to the first cell for a long time, being present usually on gametophytes bearing fertilized egg cells.

Spores were sown on soil in earthenware platters. These platters of soil had been thoroughly sterilized in an autoclave. In addition to the sowings on soil, others were made on Knop's solution and on sphagnum. The platters were covered with battery jars in such a manner as to allow ventilation, and were kept in the greenhouse at a temperature of about 70° and subjected to the usual greenhouse lighting conditions. At least a month was required for germination in some cases, and growth was slow. In one case, small prothallia were visible with the aid of a pocket lens in thirteen days after sowing, and were visible to the unaided eye in twenty-four days. Cultures of *Pteris longifolia* sown at the same time germinated more rapidly and made a great deal more rapid growth all along. Other experimenters report germination and greening of the soil in from three to seven days for the species more commonly studied, but Pickett (23) states that a period of twenty-five days elapsed between the sowing and first appearance of green in the case of *Camplosorus rhizophyllus*. The gametophytes of *Asplenium*

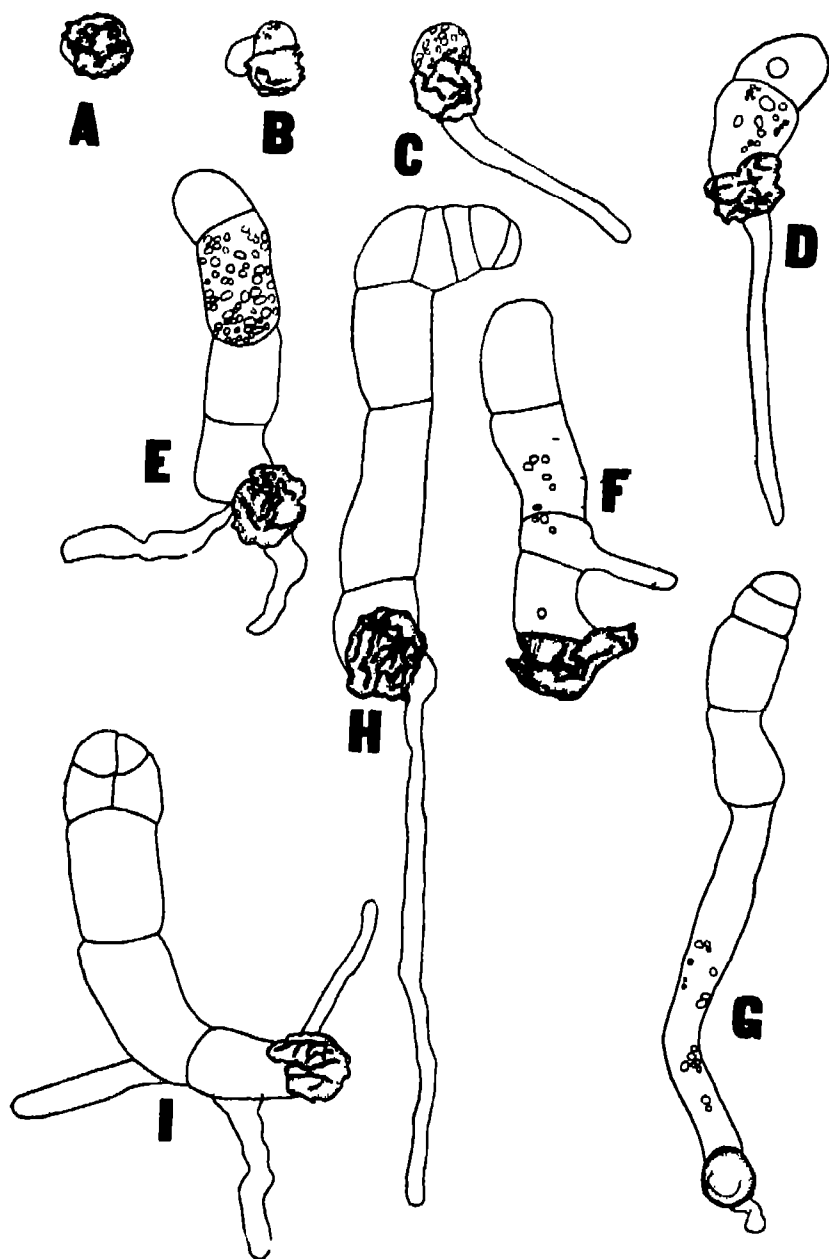


Fig 1 Germination of spore, and early divisions of prothallium, A E, and I
F, G, H, some unusual forms of the young prothallium $\times 130$

angustifolium were easily affected by a change of environment, as was shown by transference to the laboratory, which was heated by a gas stove. Growth was greatly retarded. The prothallia grew poorly on sphagnum. Most rapid growth took place on sterilized soil, while germination and growth on Knop's solution were somewhat slower. Judging from the slow growth they made, optimum conditions apparently were not obtained with most of the cultures.

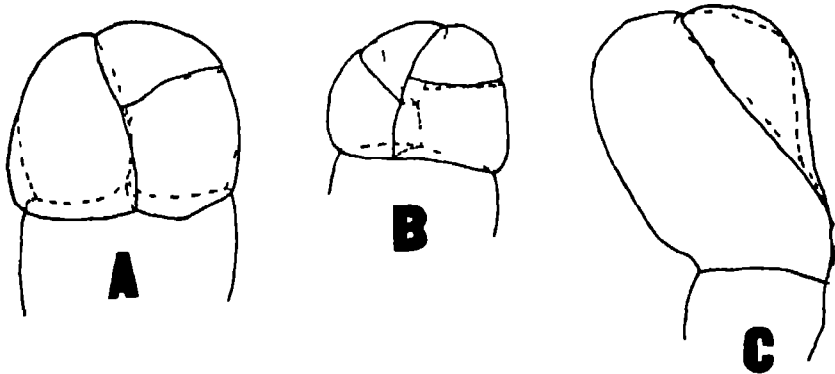


Fig. 2 Methods of division in terminal cell $\times 170$ x, apical cell

DEVELOPMENT OF PROTHALLIA

Further growth proceeds by division in a single plane for a time, (Text-Fig 1, D, E, F, G), resulting in a protonema or filament, containing as many as nine cells (Text-Fig 3, D), although division in a second plane may occur after the formation of only four cells, as shown in Text-Figure 3, B. An unusual elongation of the first cell is shown in Text-Figure 1, G. The perinium which is usually retained for some time, was not present on this filament. An irregular growth in which one or more cells were developed on the side of the young gametophyte is represented in Text-Figure 3, C. There were only a few such cases, all found growing on Knop's solution. Another peculiar behavior was frequently observed in prothallia grown on Knop's solution. After the development of a filament a few cells long, further growth was at right angles to the older cells, (Text-Figure 1, H). Probably this was caused by changing the position of the glass vessel with respect to the light. The prothallia grew prostrate on the solution. These growths closely resemble Figure 5 of Plate 22, illustrating Miss Black's paper (4) on branched cells.

Division in a second plane in the normal terminal cell takes place after six or eight transverse divisions. This division frequently occurs simultaneously in the last two cells formed

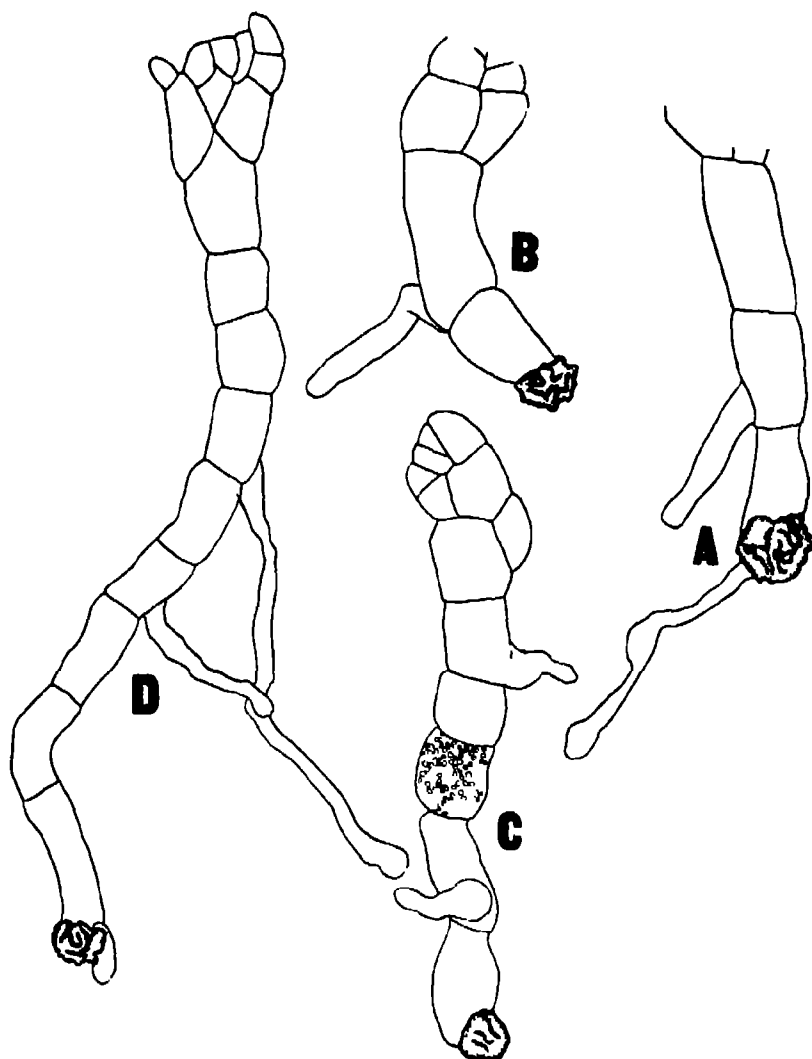


Fig 3 Young filamentous prothallia $\times 145 \times$, apical cell

(Text-Figs 1, I, 3, A) This is quite different from the usual behavior of *Onoclea Struthiopteris*, as recorded by Campbell (9), in which the first longitudinal division is oblique, and takes place

only in the terminal cell of the filament. Ordinarily, however, *Asplenium angustifolium* conforms to the method of division illustrated in Text-figures 2, A, B, 3, B. Here the terminal cell divides by formation of a longitudinal wall (Text-Fig 2, A)

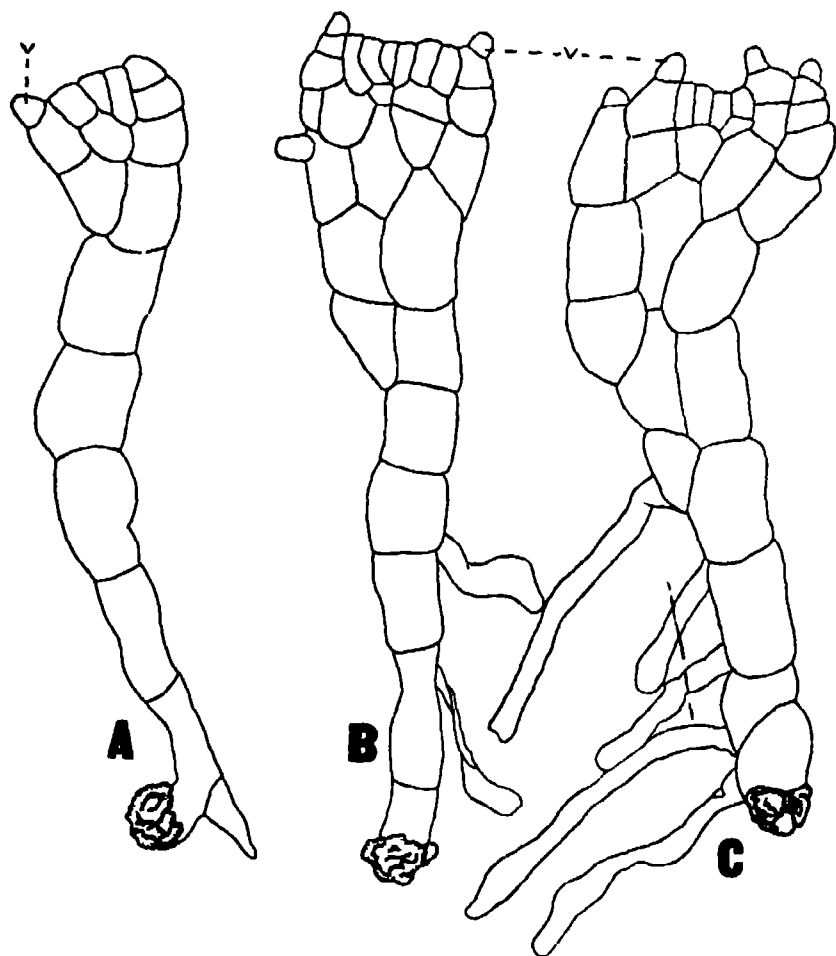


Fig 4 Young gametophytes $\times 145$ v, young glandular hairs

A somewhat oblique wall is next formed, resulting in the apical cell (x, Text-Fig 2, A). The next is a transverse wall (Text-Fig 2, B), then another longitudinal wall divides the large cell immediately below the former terminal cell (Text-Fig 3, B). Only one case resembling the method Campbell described for *O. Struthiopteris* was observed (Text-Fig 2, C).

The apical cell (x , Text-Figs 2, A, B, 3, B) is the center of growth during the subsequent development of the gameto-

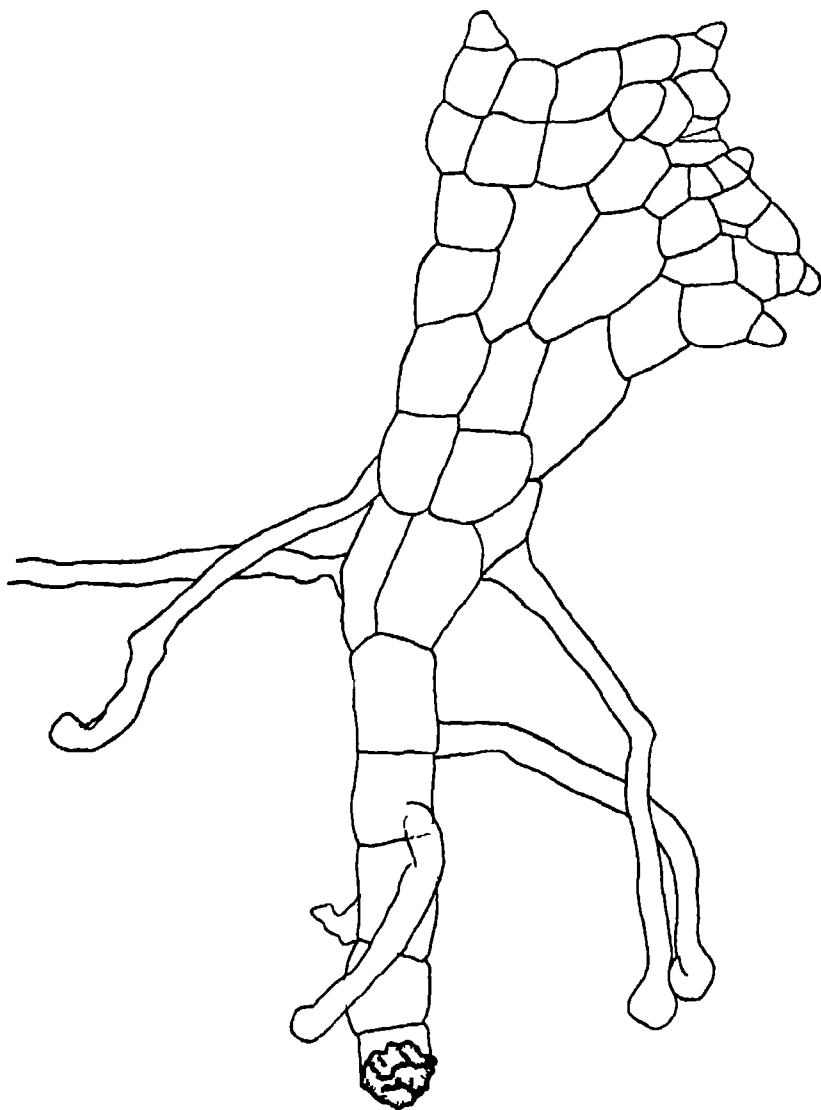


Fig 5 Young fan-shaped gametophyte $\times 150$

phyte It is sometimes difficult to point out the apical cell in the earlier stages, but it may usually be distinguished by its triangular shape

Mitotic figures have been observed frequently by the writer in the cells of the archegonial cushion, and not at all in the cells

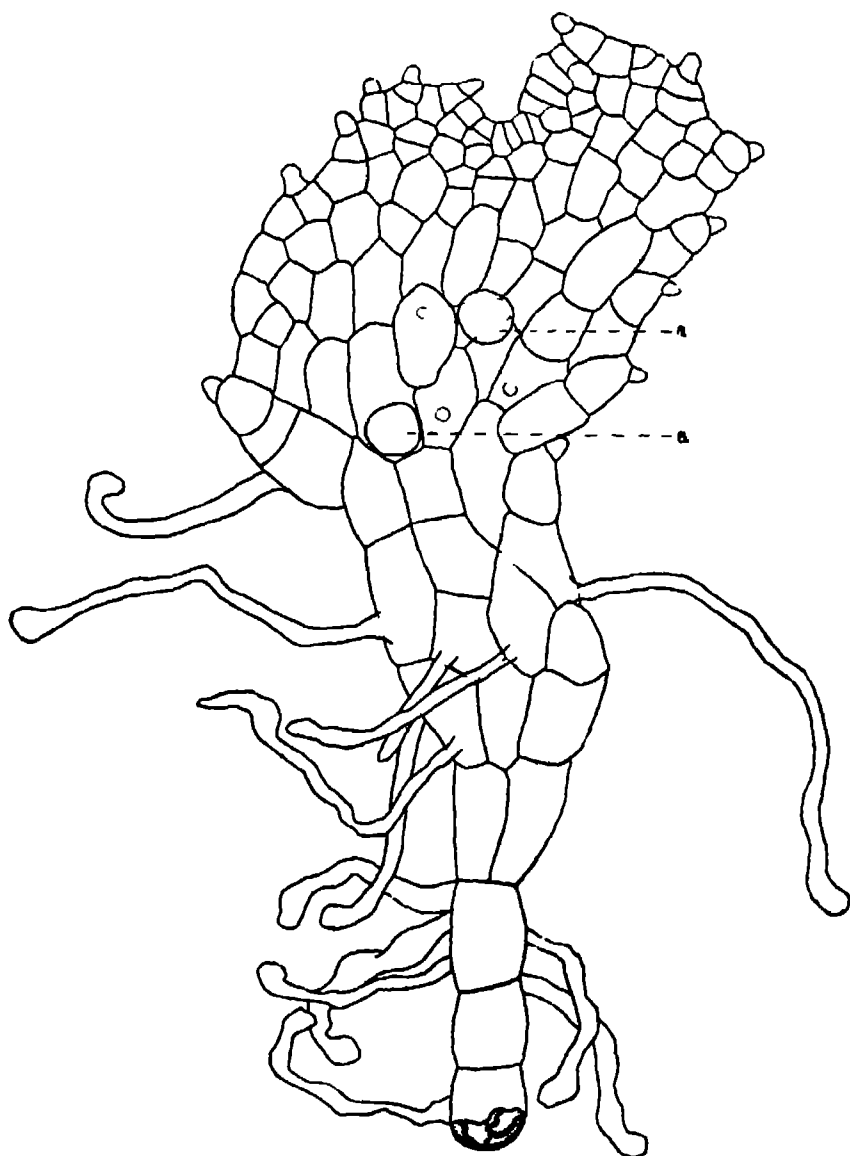


Fig 6 Young gametophyte bearing two antheridia, *a* $\times 100$

of the surrounding lobes. They occur only in the anterior part of the cushion, however, (Text-Fig 9, C). But it is

evident that cell division takes place not only in the apical cells, but in adjacent cells as well

■ A rapid widening of the upper part of the prothallium follows the appearance of the apical cell, a fan shape being

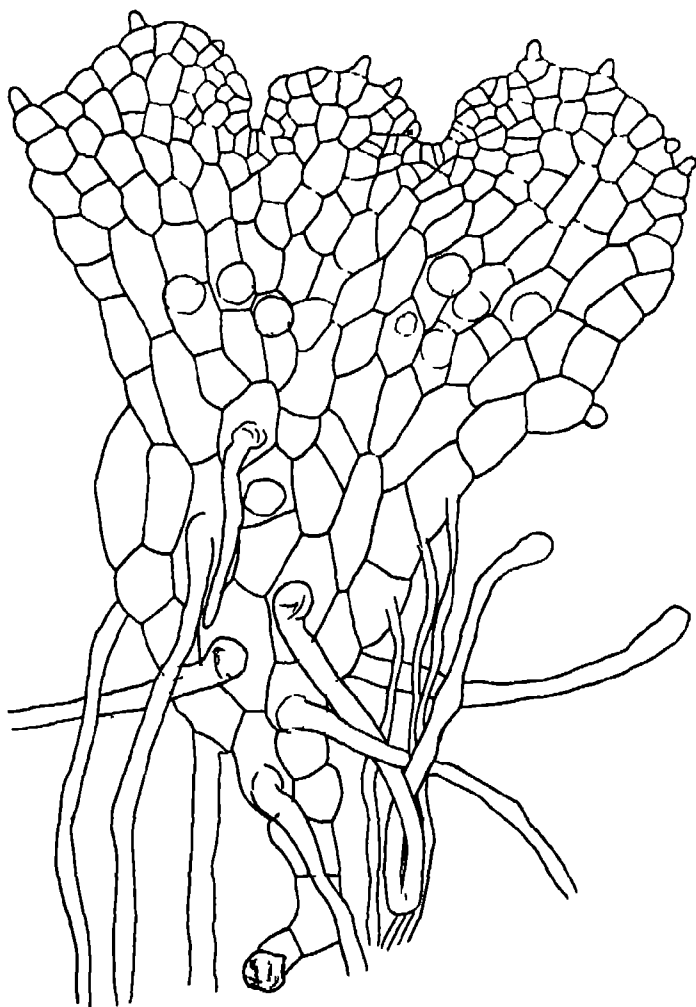


Fig 7 Young prothallium showing two apical sinuses and several antheridia
×105

assumed, (Text-Figs 3, D, 4, A, B, C, 5) By the rapid cutting off of cells on either side of the apical cell, lobes are developed, resulting in an apical sinus or indentation, which becomes deeper as the prothallium matures (Text-Figs 6, 7)

This process results eventually in the regular heart-shaped structure which characterizes most fern prothallia

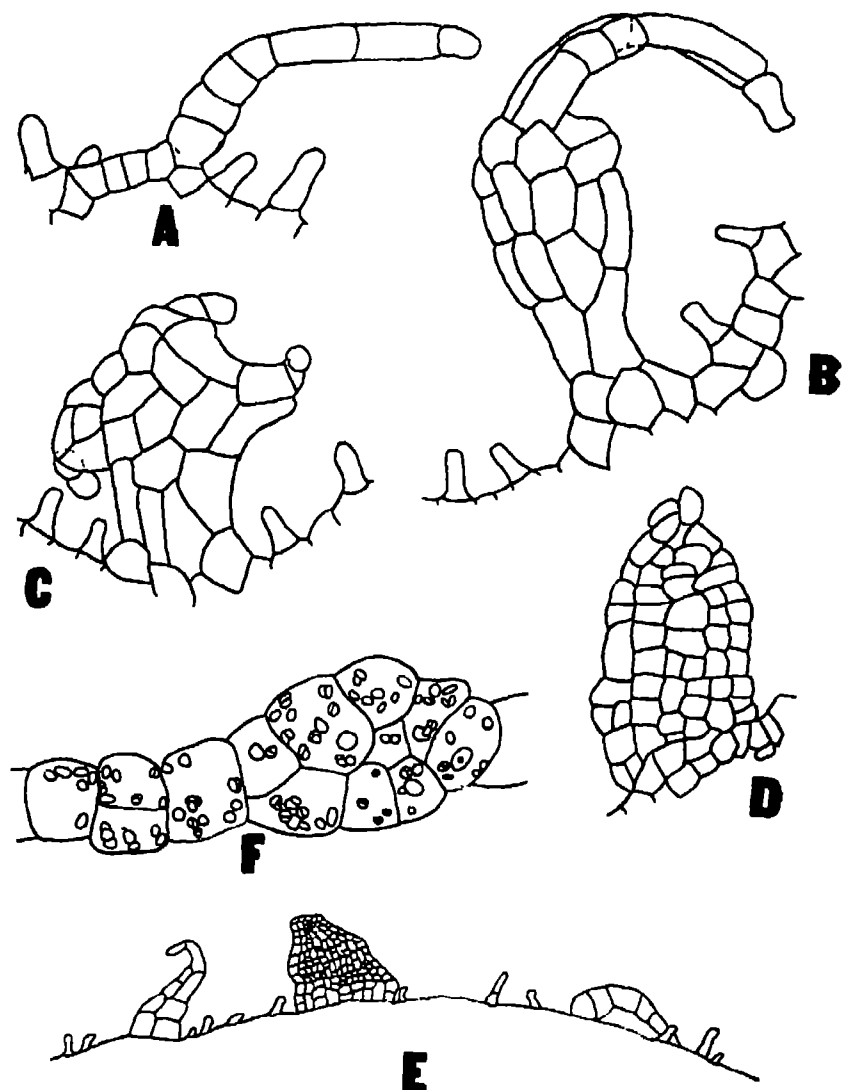


Fig 8 Proliferations found on prothallia of *A. angustifolium*
A, B, C, D, F, $\times 125$, E, $\times 50$

Very soon after the apical cell is discernible certain peculiar vegetative cells appear (v, Text-Fig 4, A, B, C), which persist throughout the life of the gametophyte Steil (28) designates

such structures as glandular hairs, and states that they occur in all species of *Aspidium* in which apogamy has been found, but that they do not occur in *Pellea* or *Pteris*

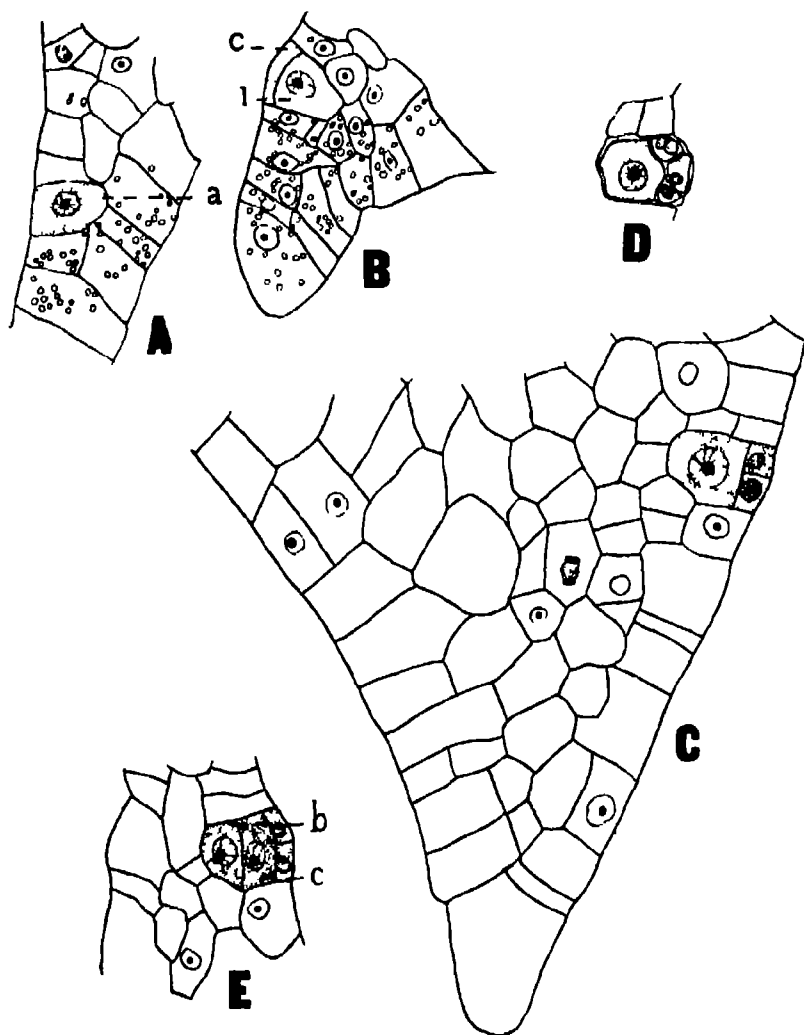


Fig 9 A a archegonium initial B c cap cell l inner cell C First division of cap cell D Second division of cap cell E First division of inner cell, b, basal cell c, central cell $\times 240$

The prothallium remains only one cell in thickness until it is about 2 mm across, before the midrib or archegonial cushion is developed around the apical sinus. This is accomplished by

the cutting off of posterior segments from the apical cell or cells. These posterior segments then divide in a plane parallel to that of the prothallium, forming a cushion two cells thick. The older cushions are several cells thick, after many more posterior segments have been cut off from the apical cells, and after more divisions in the plane of the prothallium have occurred.

Pickett (23) finds irregularity of shape to be the usual thing in *Campiosorus rhizophyllus*. In *Asplenium angustifolium* the prothallia are remarkably regular in outline. However, a few prothallia showed unusual growths or proliferations along the wings. These outgrowths were devoid of chlorophyll, and took various forms (Text-Fig 8, A-E). Several cases were found where there were two apical sinuses (Text-Fig 7). Another interesting irregularity was discovered in one of the prothallia which was sectioned (Text-Fig 8, F). Preceding and succeeding sections showed this to be a spherical cluster of cells out near the edge of the prothallium. It was entirely surrounded by only a single layer of normal cells. The cells comprising the cluster stained like the rest of the vegetative tissue, hence it was evidently simply a vegetative abnormality or proliferation.

THE DEVELOPMENT OF THE ARCHEGONIUM

In the selection of prothallia for the study of archegonia, individuals were selected which seemed to be in the desired stage of development, and were examined under the microscope. In this way the particular age of the archegonium sought for may be determined fairly accurately. The wings of each prothallium selected were clipped off almost to the cushion, to reduce to a minimum the number of worthless sections on the slide.

After careful washing in distilled water, the prothallia were placed in chromo-acetic acid containing one minim of a 2% osmic acid solution per 100 c c, for 12-36 hours. They were then washed in running water for 24 hours, and were run through the usual series of alcohols and alcohol-chloroform mixtures. Some dry erythrosin was added to the 100% alcohol to render the tiny pieces visible in the paraffin. The material was then imbedded in the usual way.

Sections were cut 5 micra thick and stained with the anilin-safranin, gentian-violet, orange G combination. The last dye was used in clove oil. Sections were examined with an oil immersion lens and drawings were made with the aid of a camera lucida.

Archegonia appear on the cushion on the ventral side of the prothallia when they are about 2 mm across. The initial cell may be easily distinguished by its dense cytoplasm, very large nucleus, and keystone shape (Text-Fig 9, A). After one becomes familiar with them, they may be found readily on most prothallia of the right age.

The first division of the initial cell results in the formation of the cap cell and the inner cell. The cap cell is thin in comparison with the latter (Text-Fig 9, B). The nucleus of the

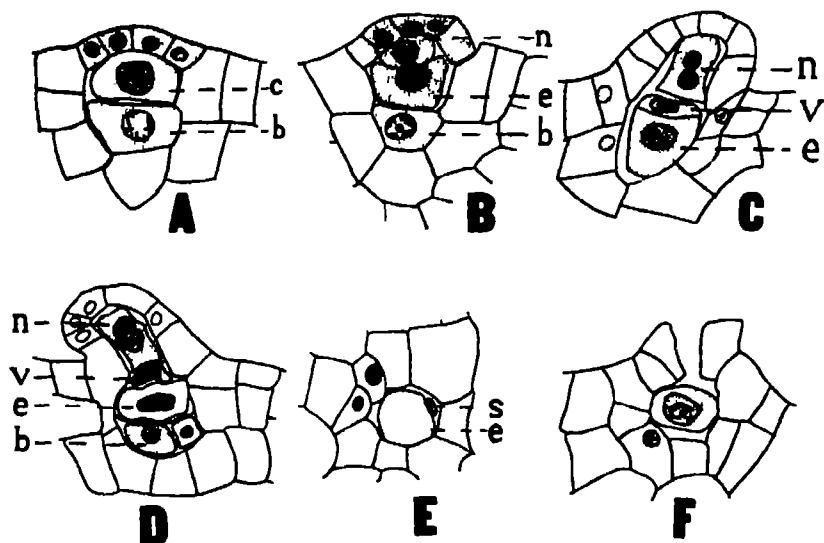


Fig 10 Stages in the development of the archegonium. A *c*, central cell, *b*, basal cell. B *n*, cell which gives rise to neck canal cell, *e*, cell which gives rise to egg and ventral canal cell, *b*, basal cell. C *n*, neck canal cell, *v*, ventral canal cell, *e*, egg. D *n*, neck canal cell, *v*, ventral canal cell, *e*, egg, *b*, basal cells. E *e*, egg, *s*, sperm. F Fertilized egg, sperm within egg nucleus. $\times 230$

inner cell is larger than that of the first cap cell or its daughter cells. The first division of the cap cell is soon followed by divisions in the two daughter cells. These divisions which are at right angles to the first, result in the formation of the four cells constituting the chimney foundation (Text-Fig 9, D). The inner cell divides into a basal and a central cell (Text-Fig 9, E). The sequence of these divisions varies somewhat, but usually the second division of the cap cell precedes the first division of the inner cell. Text-Figure 10, A, B, representing mitotic stages in the basal cells, shows that the order of division may

vary also in the basal and central cells. In subsequent divisions the basal cell gives rise to the four cells (Text-Fig 10, D) which form part of the wall of the venter. The central cell divides to form the neck canal cell, and a cell which gives rise to the egg and the ventral canal cell (Text-Fig 10, B). The neck canal cell nucleus divides, forming two nuclei without a corresponding division of the cell, as shown in Text-Fig 10, C, D. The arrangement of archegonial contents usually observed is best shown in C of this Figure. The basal cells, which are left out in C because of oblique sectioning, stained darkly in the section represented in D, just as they did in sections of younger archegonia (Text-Fig 10, A, B). The last named divisions, accompanied by the development of the archegonial neck from the four cells of the chimney foundation, complete the growth of the archegonium. When mature, the necks of the archegonia are bent backwards toward the rhizoids, as is usually the case in the Polypodiaceæ. The degeneration of the neck canal and ventral canal cells gives rise to a gelatinous substance, which swells on absorption of water, and bursts open the lid cells of the archegonium. The gelatinous substance emerges, and forms a frothy mass at the opening of the neck. In this condition fertilization takes place.

SEX IN ASPLENIUM ANGUSTIFOLIUM

Antheridia occur on the prothallia when the latter are quite young, and sometimes persist until archegonia appear, although usually the plant seems to be dioecious. No attempt was made to develop purely monoecious or dioecious plants by controlling environmental factors, but in one culture grown on an unusually concentrated Knop's solution, it was noted that antheridia were developed much earlier than in cultures grown upon sterilized soil. Archegonia were not found in the solution cultures.

Experiments having to do with the control of sex in ferns have been carried out on *Onoclea Struthiopteris* by Miss Wuist (36), Mottier (20), and others. Mottier believes that it is highly probable that the sex tendency is predetermined in the spore, and that the male tendency is dominant under good cultural conditions, but that the development of sex organs may be influenced by varying environmental conditions. This seems to be the case in *A. angustifolium*. In thickly sown cultures, antheridia are borne abundantly on the irregularly shaped prothallia as well as on those possessing the more typical

heart shape The crowded condition prevents the maturing of the prothallia and proves but little about sex, other than that the young prothallia are largely male

DEVELOPMENT OF ANTHERIDIUM

The development of the antheridium in *A. angustifolium* is entirely normal, beginning with the cutting off of a single hemispherical initial on a surface or marginal cell of the prothallium (Text-Fig 11, A, G) The first division of the initial

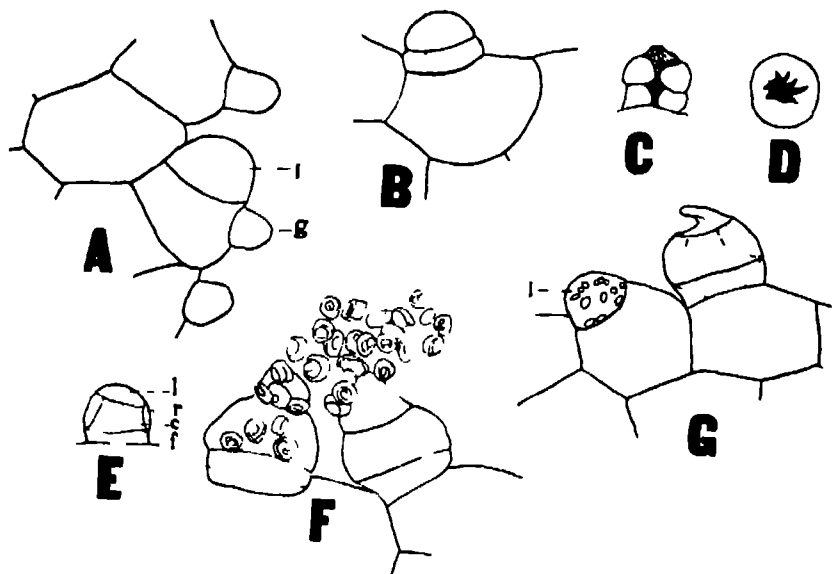


Fig 11 Stages in development of antheridium A : initial cell g, young glandular hairs B Two-celled stage C Antheridium after escape of sperms, side view D Same, top view E Mature antheridium l, lid cell, r, ring cell, c, central cell, f, funnel cell F Mature antheridia, sperms escaping from one at left G : initial cell containing chloroplasts, with old antheridium A, B F, G, $\times 255$ C, D, E, $\times 145$

results in the formation of a lower funnel cell and a dome-shaped upper cell (Text-Fig 11, B) A periclinal division in the dome-shaped cell gives rise to the central cell and an arching cover cell (Text-Fig 11, E) A final division of the cover cell results in the cap cell and the ring cell (Text-Fig 11, G) The formation of the cap and ring cells completes the development of the antheridium The central cell divides several times, giving rise to the sperm mother cells, from which the sperms or antherozooids are developed Details of this development are beyond the scope of this paper

Mature sperms are induced to escape from the antheridium by allowing the culture to become rather dry, and then transferring some of the antheridial prothallia to a drop of water on a slide. The rupture of the cap cell, swelling of funnel and ring cells, from water absorption, and consequent expulsion of the sperms, were observed under the microscope (Text-Fig 11, F). After remaining tightly coiled at the opening of the antheridium for a few seconds, the sperms suddenly uncoil and immediately swim away by means of numerous cilia. Under laboratory

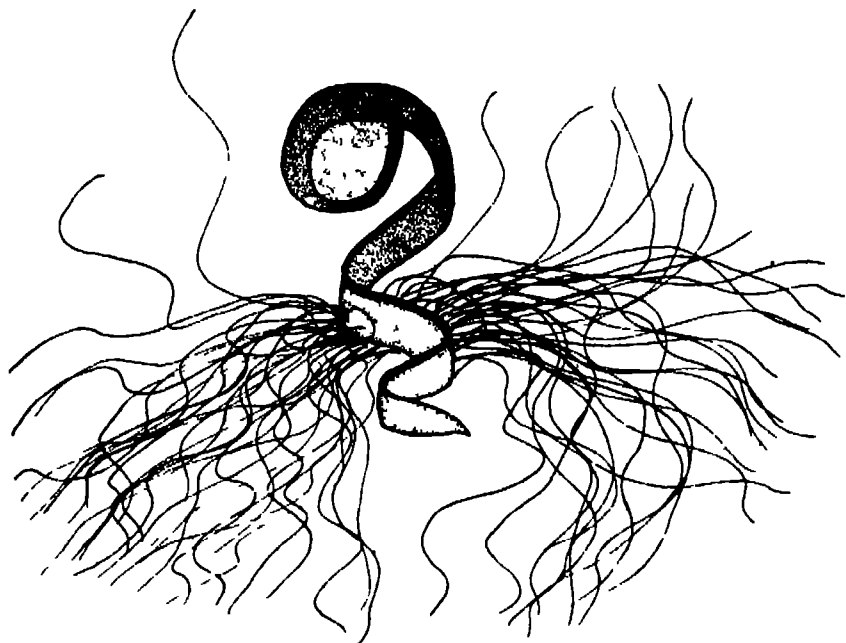


Fig 12 A mature sperm $\times 1465$

conditions locomotion may be kept up for about half an hour. Views of antheridia from which sperms have escaped are shown in Text-Figure 11, C, D, and G. A single mature sperm is represented in Text-Figure 12.

FERTILIZATION

Several sections prepared for study of fertilization showed great numbers of sperms around the neck of the archegonium. Text-Figure 10, E, shows a sperm within the venter next to the egg, and fertilization is shown in F of the same figure. In this

case, the sperm was distinguishable in the egg nucleus, but no traces of cytoplasm were left on the outside of the egg. The most of the cells of the neck of the archegonium were missing in this section.

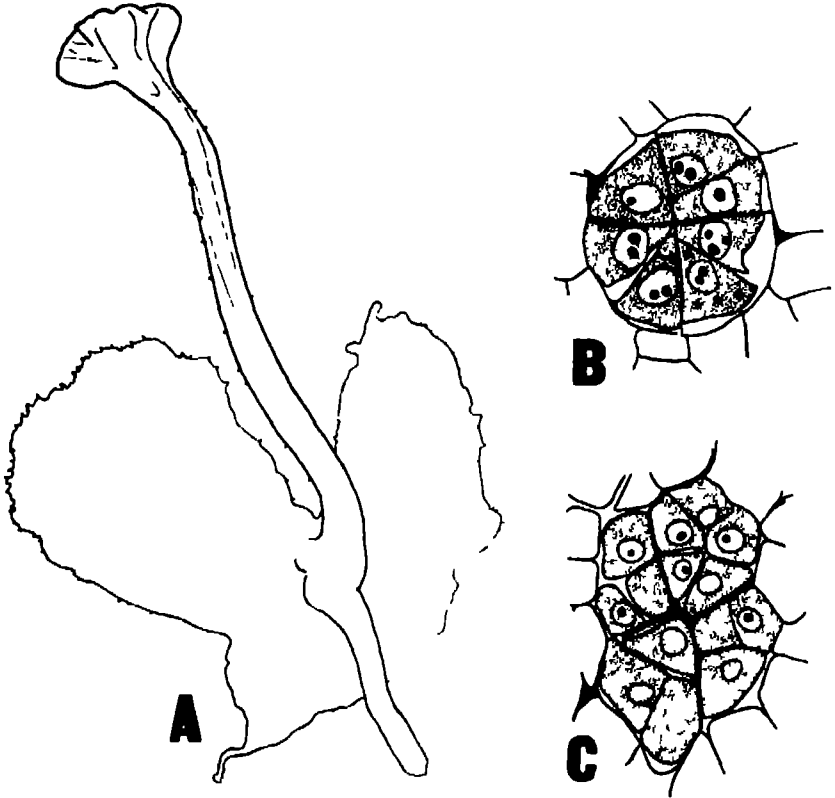


Fig 13 A Young sporophyte $\times 95$ B C Sections of young embryos, $\times 255$

In the material prepared for the study of the embryo, no sections contained the first division of the egg after fertilization, but several contained young embryos. Text Figure 13, B, shows the youngest stage found, while C of the same figure represents one somewhat older. The quadrants, from which are developed the leaf, stem, foot and root of the young sporophyte, showed up very distinctly in the embryo sections. These four parts may be readily identified in Text-Figure 13, A.

SUMMARY

1 The spores of *Asplenium angustifolium* germinate slowly. About a month is ordinarily required, although in one case small green prothallia were observed in thirteen days with the aid of a pocket lens. The fact of its slow germination, coupled with its scarcity and fragility, may be factors in a losing fight for survival of this species.

2 The steps leading to the formation of the apical cell differ from the method usually described for polypodiaceous ferns. The first division of the terminal cell is longitudinal instead of oblique, and both of the resulting cells divide transversely.

3 The protonemal filament is usually only three or four cells long when the terminal cell divides, but in some cases it is a great deal longer.

4 The perinium usually adheres throughout the life of the gametophyte.

5 The gametophyte is regularly heart-shaped. A few cases were observed where proliferations devoid of chlorophyll were developed around the edge of the prothallium. One proliferation took the form of a localized thickening of the wing.

6 The development of the archegonium conformed to the method usually described with the following exceptions: (a) The first division of the inner cell sometimes precedes and sometimes follows the formation of the chimney foundation from the cap cells. (b) The division of the central cell may precede or may follow the division of the basal cell.

7 In the development of the antheridium and the embryo, the stages usually described for ferns of this group are followed.

The writer wishes to express his great appreciation and gratitude to Professor C. E. O'Neal, of Ohio Wesleyan University, for his helpful suggestions and criticisms in the carrying on of this work.

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ADDITIONS TO THE CATALOG OF OHIO VASCULAR PLANTS FOR 1925*

JOHN H SHAFFNER

Ohio State University

Many rare plants have been added to the State Herbarium of the Ohio State University during the past year, establishing new records and extending the known ranges of various species in the state. The names of the several contributors are given in connection with each record. Through the kindness of Dr. L. B. Robinson, Curator of the Gray Herbarium of Harvard University, 15 records are published of species and varieties represented in the Gray Herbarium. It is interesting to note that some of these plants were collected by Wm. S. Sullivan, the most prominent of the early botanists of Ohio.

Those who are interested in the correct phylogeny of our plants and the proper arrangement of the species in series will find the recent papers on the Chicory family and Carrot family of value, published in this Journal by Nellie F. Henderson.

- 25 *Asplenium ruta-muraria* L. Wall-rue Spleenwort "At top of limestone Cliff" Cedar Falls, Adams Co. Mrs. Bayard Taylor
- 55 *Equisetum silvaticum* L. Wood Horsetail Ravenna, Portage Co. Raymond Dobbins
- 60 *Lycopodium inundatum* L. Bog Club-moss "Sand-pit" Holland, Lucas Co. E. L. Moseley
- 65 *Selaginella apus* (L.) Spreng. Creeping Selaginella On hillside marsh with Sphagnum, among grasses. White's Gulch, Liberty Twp., Jackson Co. Bedford Twp., and near Pomeroy, Meigs Co. Mrs. Bayard Taylor
- 65 1 *Picea abies* (L.) Karst. Norway Spruce "Naturalized from trees planted about 70 years ago. Trees of all ages from seedlings to about 50 years old are growing and forming a natural forest extending a third of a mile or more." On Phelps Creek, Huntsburg Twp., Geauga Co., near Ashtabula Co. line. Mrs. Bayard Taylor
- 68 *Pinus strobus* L. White Pine "Escaped along roadside 6 miles west of Buena Vista, in Green Twp., Adams

*Papers from the Department of Botany, The Ohio State University, No. 169

- Co About 75 trees covering about three acres of very poor hillside soil Trees vary in size from 4 in to 12 in in diameter and have a very thrifty appearance " Conrad Roth
- 69 *Pinus rigida* Mill Pitch Pine "On south-west side of hill " Buchtel, Athens Co Len Stephenson
- 71 *Pinus echinula* Mill Short-leaf Yellow Pine Many trees on south-west exposure Two miles southwest of Sugar Grove, Fairfield Co John H Schaffner Also "on southwest side of hill " Buchtel Athens Co Len Stephenson
- 76 *Taxus canadensis* Marsh American Yew "Under naturalized *Picea abies* (L) Karst Huntsburg Twp, Geauga Co Near Ashtabula Co line Mrs Bayard Taylor
- 81 *Sagittaria graminea* Mx Grassleaf Arrow-head Spencer Twp, Lucas Co E L Moseley
- 140a *Cyperus filiculmis macilentus* Fern Cleveland, Cuyahoga Co (Greenman) In Gray Herbarium
- 143 *Cyperus flavescens* L Yellow Cyperus Spencer Twp, Lucas Co E L Moseley
- 146 *Kyllinga pumila* Mx Low Kyllinga Lucas Co E L Moseley
- 155 *Eleocharis tenuis* (Willd) Schultes Slender Spike-rush Marshall Twp, Highland Co Katie M Roads
- 159 *Fimbristylis autumnalis* (L) R & S Slender Fimbristylis Holland, Lucas Co E L Moseley
- 175 *Rynchospora capillacea* Torr Capillary Beaked-rush "Prairie patches " Turkey Creek, Adams Co E Lucy Braun
- 177 *Rynchospora glomerata* (L) Vahl Clustered Beak-rush Glengary Club grounds Springfield Twp, Lucas Co E L Moseley
- 180 *Scleria pauciflora* Muhl Papillose Nut-rush Glengary Club grounds, Springfield Twp, Lucas Co E L Moseley
- 180a *Scleria pauciflora caroliniana* (Willd) Wood Milan, Erie Co (Moseley) In Gray Herbarium
- 186 *Carex muricata* L Lesser Prickly Sedge Swanton, Fulton Co E L Moseley
- 195 *Carex diandra* Schr Lesser Panicked Sedge Castalia, Erie Co E L Moseley

- 241a *Carex laxiflora patulifolia* (Dew) Carey Columbus, Franklin Co (Gleason) Cleveland, Cuyahoga Co (Beardslee) In Gray Herbarium
- 276a *Carex oederi pumila* (Coss & Germ) Fern Castalia prairie, Erie Co (Moseley) In Gray Herbarium
- 291 *Carex typhina* Mx Cat-tail Sedge "Woods north of Nevada," Wyandot Co E L Moseley
- 298 *Bromus hordeaceus* L Soft Chess "Prairie patch " Turkey Creek, Adams Co E Lucy Braun
- 300 1 *Bromus commutatus* Schrad In Hillsboro and in Washington Twp , Highland Co Katie M Roads
- 310 1 *Festuca obtusa* Spring Blunt-glumed Fescue-grass "Common in two woods in Washington Twp , " Highland Co Katie M Roads
- 310 2 *Festuca rubra* L Red Fescue-grass Hillsboro, Highland Co Katie M Roads
- 316 *Panicularia septentrionalis* (Hitchc) Bickn American Floating Manna-grass Substitute this name for *P fluitans* (L) Ktz and add to the record of distribution "In pond, sweet gum-pin oak woods " Between White Oak and Sardinia, Brown Co E Lucy Braun
- 321 1 *Uniola latifolia* Mx Broad-leaf Spike-grass On lower part of Ohio river bluff Coal Grove, Lawrence Co John H Schaffner
- 328 *Poa autumnalis* Muhl Flexuous Spear-grass In a wood near Hillsboro, Highland Co Katie M Roads
- 334 *Eragrostis pectinacea* (Mx) Steud Purple Love-grass Hillsboro, Highland Co Katie M Roads
- 344 *Koeleria cristata* (L) Pers Crested Koeler-grass Two miles north of Whitehouse, Lucas Co E L Moseley
- 347 *Triplasis purpurea* (Walt) Chapm Purple Sand-grass Marblehead peninsula, Ottawa Co E L Moseley
- 351 *Danthonia compressa* Aust Flattened Wild-oat-grass Near Hillsboro, Highland Co Katie M Roads
- 364 *Agropyron caninum* (L) R & S Awned Wheat-grass Two miles north of Whitehouse, Lucas Co E L Moseley
- 375 *Hordeum jubatum* L Squirrel-tail Barley This grass was seen on a trip through northwestern Ohio around Kenton, Hardin Co , Lima, Allen Co , Van Wert, Van Wert Co , Paulding and Antwerp, Paulding Co , Hicksville, Defiance Co , and Bryan and Montpelier, Williams Co John H Schaffner

- 378 *Capriola dactylon* (L) Ktz Bermuda-grass "Well established on grassy slope, University of Cincinnati Campus " Cincinnati, Hamilton Co E Lucy Braun
- 383 *Sporobolus asper* (Mx) Kunth Longleaf Rush-grass Along New York Central R R, Spencer Twp, Lucas Co E L Moseley
- 385 *Sporobolus neglectus* Nash Small Rush-grass "Prairie patches " Turkey Creek, Adams Co E Lucy Braun
- 402 *Muhlenbergia racemosa* (Mx) B S P Marsh Muhlenbergia Whitehouse, Lucas Co E L Moseley
- 409 *Stipa spartea* Trin Porcupine-grass North of Whitehouse, Lucas Co E L Moseley
- 419 *Panicum agrostoides* Spreng Agrostis-like Panic-grass Swanton Twp, Lucas Co "Abundant in a low meadow " E L Moseley
- 427 *Panicum philadelphicum* Bernh Philadelphia Panic-grass "Marly soil " Turkey Creek, Adams Co E Lucy Braun
- 436 *Panicum boreale* Nash Northern Panic-grass Whitehouse, Lucas Co E L Moseley
- 446 *Panicum commutatum* Schultes Variable Panic-grass Washington Twp, Highland Co Katie M Roads
- 452 *Syntherisma ischaemum* (Schreb) Nash Small Crab-grass Along roadside Haverhill, Scioto Co John H Schaffner
- 456 1 *Paspalum circulare* Nash Round-flowered Paspalum Portsmouth, Scioto Co Conrad Roth Also at Coal Grove, Lawrence Co John H Schaffner
- 481 1 *Hemerocallis flava* L Yellow Day-lily "On the roadside" near Hillsboro, Highland Co Katie M Roads
- 481 2 *Nothoscordum bivalve* (L) Britt Yellow False-garlic Springfield, Clark Co (Sullivant, Semples) In Gray Herbarium
- 484 *Allium cepa* L Common Onion Escaped along roadside South Charleston, Clark Co John H Schaffner
- 498 *Stenanthium robustum* Wats Stout Stenanthium "In swampy soil " White's Gulch, Liberty Twp, Jackson Co Mrs Bayard Taylor
- 499 *Chamaelirium luteum* (L) Gr Chamaelirium "On hillside " White's Gulch, Liberty Twp, Jackson Co Mrs Bayard Taylor

- 500 *Triantha glutinosa* (Mx) Baker Glutinous Triantha
"Along New York Central R R ditch " Swanton
Twp , Lucas Co E L Moseley
- 504 *Trillium declinatum* (Gr) Gleason Drooping Trillium
Maroon-flowered variety Fort Hill, Highland Co
Katie M Roads
- 530 *Tradescantia reflexa* Raf Reflexed Spiderwort White's
Gluch, Liberty Twp , Jackson Co Mrs Bayard Taylor
- 544 *Juncus articulatus* L Jointed Rush Neapolis, Lucas
Co E L Moseley
- 550 *Juncus scirpoides* Lam Scirpus-like Rush White-
house, Lucas Co E L Moseley
- 552 1 *Juncoides bulbosum* (Wood) Small Bulb-bearing Wood-
rush "Rather common in a wood" in Washington
Twp , Highland Co Katie M Roads
- 553 *Xyris flexuosa* Muhl Slender Yellow-eyed-grass Two
miles north of Whitehouse, Lucas Co E L Moseley
- 557 1 *Iris germanica* L Common Iris Beside a swampy
place containing Cat-tails in a grassy meadow Spon-
taneous, either from seed or rhizomes Near Columbus,
Franklin Co John H Schaffner
- 557 2 *Iris hexagona* Walt Southern Blue-flag Toledo,
Lucas Co (Young) In Gray Herbarium
- 564 *Cypripedium reginae* Walt Showy Lady's-slipper Glen-
gary Club grounds, Springfield Twp , Lucas Co E L
Moseley
- 575 *Blephariglotis ciliaris* (L) Rydb Yellow Fringed-
orchis Two miles north of Whitehouse, Lucas Co
E L Moseley
- 596 *Liparis loeselii* (L) Rich Fen Twayblade "Sand
pit," Holland, Lucas Co E L Moseley
- 600 *Corallorrhiza maculata* Raf Large Coral-root "In a
beech wood," Washington Twp , Highland Co Katie
M Roads
- 601 *Corallorrhiza wisteriana* Conrad Wister's Coral-root
Washington Twp , Highland Co Katie M Roads
- 602 *Corallorrhiza odontorrhiza* (Willd) Nutt Small-flowered
Coral-root Marshall Twp , Highland Co Katie M
Roads
- 604 *Magnolia tripetala* L Umbrella Magnolia White's
Gulch, Liberty Twp , Jackson Co "Abundant in the
locality in the bottom and on talus slopes " Mrs
Bayard Taylor

- 614 *Ranunculus repens* L Creeping Buttercup "Rare, the patch from which this plant was taken has maintained itself through several rotations of crops, but has not spread very much " Tyler Farm, Perry, Lake Co F J Tyler
- 618 *Ranunculus arvensis* L Corn Crowfoot Columbus, Franklin Co "Introduce with packing material," (W C Werner) In Gray Herbarium
- 619 *Ranunculus obtusiusculus* Raf Lance-leaf Buttercup "Shallow pools, pin oak woods " Between White Oak and Sardinia, Brown Co E Lucy Braun
- 632 *Delphinium exaltatum* Ait Fall Larkspur "Prairie patches " Turkey Creek, Adams Co E Lucy Braun
- 669 1 *Eschscholtzia californica* Cham California Poppy Spontaneous after cultivation and seeding abundantly Columbus, Franklin Co John H Schaffner
- 687 *Camelina sativa* (L) Crantz Common False-flax "Cultivated fields " Perry, Lake Co F J Tyler
- 703 *Thlaspi arvense* L Field Penny-cress Columbus, Franklin Co "First collected in the locality in 1918, persistent ever since " C J Willard
- 719 *Barbarea verna* (Mill) Aschers Early Winter-cress Portsmouth, Scioto Co Conrad Roth
- 733 *Cardamine rotundifolia* Mx Roundleaf Bitter-cress Ironton, Lawrence Co Lillian E Humphrey
- 742 2 *Lunaria annua* L Common Honesty "Spreading from cultivation " Westerville, Franklin Co W H Camp
- 775 *Linum virginianum* L Virginia Flax Two miles north of Whitehouse, Lucas Co E L Moseley
- 809 *Chamaesyce rafinesqui* (Greene) Small (*Euphorbia hirsuta* (Torr) Wieg) Hairy Spurge Perkins, Erie Co (Moseley), Painesville, Lake Co (W C Werner) In Gray Herbarium Holland, Lucas Co E L Moseley
- 817 *Malva sylvestris* L High Mallow Buchtel, Athens Co Len Stephenson
- 824 *Althaea rosea* L Hollyhock "General escape in waste places and along roadsides " Washington Twp, Highland Co Katie M Roads
- 828 1 *Hibiscus syriaca* L Shrubby Hibiscus "Propagates itself readily from seed along streets and in waste places" near Hillsboro, Highland Co Katie M Roads

- 836 *Hypericum kalmianum* L Kalm's St John's-wort
Neapolis, Lucas Co E L Moseley
- 846 *Hypericum majus* (Gr) Britt Large Canadian St
John's-wort Neapolis, Lucas Co E L Moseley
- 848 *Hypericum drummondii* (Grev & Hook) T & G
Drummond's St John's-wort "In a meadow" Fort
Ancient, Warren Co, Hillsboro, Highland Co Katie
M Roads
- 849 *Sarothra gentianoides* L Orange-grass "In a pasture
lot" Hillsboro, Highland Co Katie M Roads
Buchtel, Athens Co Len Stephenson
- 850 *Triadenum virginicum* (L) Raf Marsh St John's-wort
Morgan Swamp, Ashtabula Co H C Beardslee and
F J Tyler
- 858 *Lechea leggettii* Britt & Holl Spencer Twp, Lucas Co
E L Moseley
- 858 1 *Lechea intermedia* Legg Large-podded Pinweed Spencer
Twp, Lucas Co E L Moseley
- 873 *Viola pallens* (Banks) Brain Woodland White Violet
Delaware Co Rufus Crane
- 875 *Viola affinis* Le Conte Thinleaf-Blue Violet "Swamp
woods," Delaware Co Rufus Crane The annotation,
"General and abundant," in the catalog is a printer's
mistake The above specimen is the only one in the
herbarium at present
- 884 *Viola sagittata* Ait Arrowleaf violet Portsmouth,
Scioto Co Conrad Roth
- 912 *Silene latifolia* (Mill) Britt & Rend Bladder Campion
On banks of Taylorsville Conservancy dam, Mont-
gomery Co John H Schaffner
- 912 1 *Silene cseres* Baumg (S fabaria Sibth & Son) Balkan
Campion "Collected on Erie Dump about 2 miles
west of Phalanx station Evidently established"
Phalanx, Trumbull Co From Southeastern Europe
Almon N Rood
- 920 *Silene caroliniana* Walt Carolina Catchfly "In a
cleft on a hillside at Fort Hill," Highland Co Katie
M Roads
- 955 *Chenopodium boscianum* Moq Bosc's Goosefoot New
Philadelphia, Tuscarawas Co V Sterki
963. *Kochia scoparia* (L) Roth Mock-cypress Abundantly
spontaneous in a field after cultivation Columbus,
Franklin Co John H Schaffner

- 980 *Tracaulon arifolium* (L) Raf Halberd-leaf Tear-thum "Very abundant in the artificial ditches at Fort Ancient," Warren Co Katie M Roads
- 983 *Persicaria amphibia* (L) S F Gr Water Persicaria "Railroad bank north of Carey," Wyandot Co E L Moseley
- 995 *Polygonum buxiforme* Small Shore Knotweed Hillsboro, Highland Co Katie M Roads
- 998 *Polygonum tenue* Mx Slender Knotweed Two miles north of Whitehouse, Lucas Co E L Moseley
- 1039 1 *Rosa rugosa* Thunb Japanese Rose "Escaped from cultivation " Beach of Lake Erie Perry, Lake Co F J Tyler
- 1040 1 *Rosa canina* L Dog Rose From Europe Escaped near Westerville, Franklin Co W H Camp
- 1090 *Prunus cuneata* Raf Appalachian Cherry North of Whitehouse, Lucas Co E L Moseley
- 1098 *Chamaecrista nictitans* (L) Moench Sensitive-pea Buchtel, Athens Co Len Stephenson and John H Schaffner
- 1131 *Robinia viscosa* Vent Claminy Locust Buchtel, Athens Co Len Stephenson and John H Schaffner
- 1131 1 *Robinia hispida* L Rose Acacia Escaped from cultivation Buchtel, Athens Co Len Stephenson and John H Schaffner
- 1138 *Meibomia pauciflora* (Nutt) Ktz Few-flowered Tick-trefoil Washington Twp, Highland Co Katie M Roads
- 1138 1 *Meibomia arenicola* Vail (*Desmodium lineatum* (Mx) D C Sand Tick-trefoil Perkins, Erie Co (Moseley) In Gray Herbarium Prof Moseley has found it recently north of Holland, Lucas Co
- 1149 *Meibomia marylandica* (L) Ktz Maryland Tick-trefoil Springfield Twp, Lucas Co E L Moseley
- 1150 *Meibomia obtusa* (Muhl) Vail Ciliate Tick-trefoil. Glengary Club grounds, Springfield Twp, Lucas Co E L Moseley
- 1153 *Lespedeza nuttallii* Darl Nuttall's Bush-clover "Clearings and shale slopes " Turkey Creek, Adams Co E Lucy Braun
- 1157 *Lespedeza virginica* (L) Britt Slender Bush-clover On clearings and shale slopes " Mineral Springs, Adams

- Co E Lucy Braun Also Chesapeake, Lawrence Co
R B Gordon
- 1158 *Lespedeza simulata* Mack & Bush Intermediate Bush-
clover Castalia, Erie Co (Moseley) In Gray
Herbarium
- 1161 1 *Vicia villosa* Roth Hairy Vetch Appears to be quite
generally escaped in the state and is persistent in fields
after cultivation A weed in wheatfields
- 1173 1 *Lathyrus latifolius* L Everlasting Pea "Escaped from
cultivation along roadsides " Hillsboro, Highland Co
Katie M Roads
- 1173 2 *Chloria mariana* L Butterfly-pea White's Gulch,
Liberty Twp, Jackson Co "On sandy banks under
pine trees " Mrs Bayard Taylor
- 1199 *Parsonia petiolata* (L) Rusby Blue Waxweed "Creek
bottom " Perry, Lake Co F J Tyler
- 1200 *Rhexia virginica* L Virginia Meadow-beauty Blue
Creek, Adams Co Conrad Roth
- 1286 *Alnus incana* (L) Wild Hoary Alder In swampy
place Loudonville, Ashland Co Cedar Swamp, Cham-
paign Co John H Schaffner Also Western part of
Lucas Co E L Moseley
- 1338 *Epilobium lineare* Muhl Linear-leaf Willow-herb Mor-
gan Swamp, 5 miles east of Hartsgrrove, Ashtabula Co
H C Beardslee and F J Tyler
- 1342 *Convolvulus spithameus* L Upright Bindweed Ironton,
Lawrence Co Lillian E Humphrey
- 1344 *Raimannia laciniata* (Hill) Rose Cutleaf Evening-
primrose Whitehouse, Lucas Co E L Moseley
- 1357 1 *Cucurbita lagenaria* L Bottle Gourd "Accidental
along road," Hillsboro, Highland Co Katie M Roads
- 1376 *Steronema lanceolatum* (Walt) Gr Lanseleaf Yellow
Loosestrife North of Whitehouse, Lucas Co E L
Moseley
- 1395 *Azalea lutea* L Flame Azalea Ironton, Lawrence Co
Lillian E Humphrey
- 1401 *Oxydendrum arboreum* (L) DC Sorrel-tree Buchtel,
Athens Co Len Stephenson

STYRACACEÆ Storax Family

- 1415 1 *Styrax grandifolia* Ait Large-leaf Storax "On the crest of the north end of a high ridge, near 'Buffalo Beat,' on an outcropping ledge of limestone " Buchtel, Athens Co Len Stephenson
- 1455 *Chionanthus virginica* L Fringetree Liberty Twp, Jackson Co Mrs Bayard Taylor
- 1464 *Gentiana quinquefolia* L Stiff Gentian Cedar Falls, Adams Co Mrs Bayard Taylor
- 1465 *Gentiana crinita* Froel Fringed Gentian Grand River Valley, Madison, Lake Co H C Beardslee and F J Tyler
- 1470 *Gentiana villosa* L Striped Gentian "Open woods " Cedar Falls, Adams Co Mrs Bayard Taylor
- 1472 *Obolaria virginica* L Pennywort Near Hillsboro, Highland Co Katie M Roads
- 1481 *Acerates floridana* (Lam) Hitch Florida Milkweed On hillsides, Buchtel, Athens Co Len Stephenson Also Whitehouse, Lucas Co E L Moseley
- 1481 1 *Asclepiodora viridis* (Walt) Gr Oblong-leaf Green Milkweed Cedar Mills, Adams Co Conrad Roth
- 1484 *Asclepias purpurascens* L Purple Milkweed Sugar Grove, Fairfield Co On open hillside John H Schaffner Also Minford, Scioto Co Conrad Roth
- 1488 *Asclepias amplexicaulis* J E Sm Blunt-leaf Milkweed Sandy Springs, Adams Co Conrad Roth
- 1500a *Datura stramonium* L Jimson-weed Purple-stemmed variety General in the state
- 1500b *Datura stramonium* L Jimson-weed Smooth-podded variety Escaped from cultivation Columbus, Franklin Co John H Schaffner
- 1529 *Conobea multifida* (Mx) Benth Conobea "On limestone " Greenbrier District, Adams Co Conrad Roth
- 1555 *Dasystoma virginica* (L) Britt Smooth False Foxglove "Openings, pin oak woods " Westboro, Clinton Co E Lucy Braun
- 1561 *Castilleja coccinea* (L) Spreng Scarlet Painted-cup "Meadows and thickets, along streams " Turkey Creek, Adams Co E Lucy Braun Greenbrier District, Adams Co Conrad Roth

- 1568 *Chaenorrhinum minus* (L) Lange Lesser Toadflax
"Railroad tracks," Westboro, Clinton Co E Lucy
Braun Also north of Carey, Wyandot Co E L
Moseley and V F Alspach Also Perry, Lake Co
F J Tyler
- 1570 *Kickxia elatine* (L) Dum Sharp-pointed Toadflax
Chesapeake, Lawrence Co R B Gordon
- 1597 1 *Myosotis macrantha* Pallas Small-flowered Forget-me-
not Naturalized from Europe Ashtabula, Ashtabula
Co (Sara F Goodrich, no 552) In Gray Herbarium
- 1607 *Echium vulgare* L Blueweed Abundant in pastures and
along roads South Charleston, Clark Co John H
Schaffner
- 1627 *Scutellaria integrifolia* L Hyssop Skullcap Portsmouth,
Scioto Co Conrad Roth
- 1641 1 *Koelia leptodon* (Gr) Small (*Pycnanthemum leptodon*
Gr) Springfield, Clark Co (Sullivant) In Gray
Herbarium
- 1653 *Mentha citrata* Ehrh Bergamot Mint Buchtel, Athens
Co Len Stephenson
- 1669 1 *Leonurus marrubiastrum* L Hoarhound Motherwort
"In fields " Naturalized from Europe Milford, Cler-
mont Co E Lucy Braun
- 1681 *Monarda punctata* L Horsemint "Sandy soil "
Bowling Green, Wood Co E L Moseley
- 1686 *Salvia lyrata* L Lyreleaf Sage White's Gulch, Liberty
Twp, Jackson Co Mrs Bayard Taylor
- 1698 *Aralia spinosa* L Angelica-tree Escaped from cul-
tivation Buchtel, Athens Co Len Stephenson and
John H Schaffner
- 1704 *Eryngium aquaticum* L Rattlesnake-master "Level,
poorly drained fields " California, Hamilton Co E
Lucy Braun
- 1714 1 *Hipposelinum levisticum* (L) Britt Lovage "Along
a fence in a waste lot " Escaped from cultivation in
Penn Twp, Highland Co From S Europe Katie M
Roads
- 1722 1 *Thaspium pinnatifidum* (Buckl) Gr Cutleaf Meadow-
parsnip "Lower slope of railroad embankment, level
upland " Hamlet, Clermont Co E Lucy Braun
- 1734 *Eulophus americanus* Nutt Eastern Eulophus Colum-
bus, Franklin Co (Sullivant "Extremely rare") In
Gray Herbarium

- 1735 *Pimpinella saxifraga* L Pimpernel Sycamore, Wyandot Co (Rusby, 1878) In Gray Herbarium
- 1753 *Houstonia ciliolata* Torr Fringed Houstonia Hillsboro, Highland Co Katie M Roads
- 1760 *Diodia teres* Walt Rough Buttonweed Chesapeake, Lawrence Co R B Gordon
- 1776 1 *Viburnum molle* Mx Soft-leaf Arrow-wood "Beaver pond flat," Adams Co E Lucy Braun In Herbarium, University of Cincinnati
- 1794 *Lonicera japonica* Thunb Japanese Honeysuckle Escaped from cultivation and spreading at Buchtel, Athens Co Len Stephenson and John H Schaffner
- 1800 *Lonicera dioica* L Smooth-leaf Honeysuckle Whitehouse, Lucas Co E L Moseley
- 1817 *Lobelia puberula* Mx Downy Lobelia Shawnee Forest Preserve, Union Twp, Scioto Co Conrad Roth
- 1834 *Rudbeckia fulgida* Ait Orange Cone-flower "Fields" Blanchester, Clinton Co E Lucy Braun
- 1835a *Rudbeckia speciosa* sullivanti (Boy & Bead) Rob Columbus, Franklin Co (Sullivant) In Gray Herbarium
- 1840 *Helianthus occidentalis* Ridd Fewleaf Sunflower "Prairie ridge on Cedarville marl" Turkey Creek, Adams Co E Lucy Braun
- 1857 *Phaethusa helianthoides* (Mx) Britt Sunflower Crown-beard Washington Twp, Highland Co Katie M Roads
- 1873 *Bidens aristosa* (Mx) Britt Western Tickseed Springfield Twp, Lucas Co E L Moseley
- 1876 *Polymnia uvedalia* L Yellow Leaf-cup "Apparently introduced into the locality recently" Two and one-half miles north of New Philadelphia, Tuscarawas Co V Sterki
- 1886 *Helenium nudiflorum* Nutt Purple-headed Sweezweed "Growing abundantly in an old pasture" Perry, Lake Co F J Tyler
- 1901 *Grindelia squarrosa* (Pursh) Dun Broadleaf Gumplant "Engle's pasture next to Wabash R R" South of Swanton, Fulton Co E L Moseley
- 1903 *Chrysopsis mariana* (L) Nutt Maryland Golden-aster Shawnee Forest Preserve, Union Twp, Scioto Co Conrad Roth

- 1909 *Solidago erecta* Pursh Slender Goldenrod Mineral Springs, Adams Co E Lucy Braun
- 1922 *Solidago rigida* L Stiff Goldenrod "Prairie patches " Turkey Creek, Adams Co E Lucy Braun
- 1929 *Sericocarpus linifolius* (L) B S P Narrowleaf White-top Aster "Oak-blueberry association Sandy ridge " Peach Mt , Adams Co E Lucy Braun
- 1934 *Aster azureus* Lindl Azure Aster "Steep clay bluffs, prairie openings " Miamiville, Clermont Co E Lucy Braun
- 1941 *Aster patens* Ait Late Purple Aster Portsmouth, Scioto Co Conrad Roth
- 1948 *Aster junceus* Ait Rush Aster Lucas Co E L Moseley
- 1951 *Aster vimineus* Lam Small White Aster Buchtel, Athens Co Len Stephenson
- 1957 *Aster faxoni* Porter Faxon's Aster Marblehead peninsula, Ottawa Co E L Moseley
- 1976 1 *Eupatorium incarnatum* Walt Pink Thoroughwort Chesapeake, Lawrence Co R B Gordon
- 1977 *Eupatorium coelestinum* L Mist-flower Along roadside, just below Chillicothe, Ross Co John H Schaffner
- 1982 *Laciniaria scariosa* (L) Hill Large Blazing-star "Prairie patches," Turkey Creek, Adams Co E Lucy Braun
- 1987 *Vernonia missurica* Raf Missouri Ironweed Whitehouse, Lucas Co E L Moseley
- 2019 1 *Carduus acanthoides* L Spiny Plumeless Thistle Near Ashville, Pickaway Co F H Parks Also near Urbana, Champaign Co D D Dowds
- 2035 3 *Apargia autumnale* (L) Hoffm Autumnal Hawkbit The plant is the Var *pratensis* Trumbull, Ashtabula Co Collector, Earl Dodge F J Tyler
- 2039 *Sonchus arvensis* L Field Sow-thistle "Rare but widely distributed in the country Usually growing in rich low ground near railroads " Tyler Farm, Perry, Lake Co F J Tyler
- 2046 *Lactuca sagittifolia* Hill Arrow-leaf Lettuce Hillsboro, Highland Co and Fort Ancient, Warren Co Katie M Roads

- 2054 *Nabalus crepidineus* (Mx) DC Corymbed Rattlesnake-root On Little Darby Creek, South of National Road, Madison Co R B Gordon
- 2064 *Crepis capillaris* (L) Wallr Smooth Hawksbeard. "Lawns in Perry Village " Perry, Lake Co F J. Tyler

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REPORT OF THE THIRTY-SIXTH ANNUAL MEETING OF THE OHIO ACADEMY OF SCIENCE

The Thirty-sixth Annual Meeting of the Ohio Academy of Science was held at the Ohio State University, Columbus, Ohio, April 9 and 10, under the presidency of Dr Paul M Rea. About one hundred fifty members, old and new, were in attendance. Sixty-nine new members were elected, thus bringing the total membership of the Academy up to 442 at the close of the meeting.

The following is the general program of the meeting

FRIDAY, APRIL 9

- 9:00 A M —Business meeting
- 10:00 A M —Reading of papers in general session
- 1:00 P M —Reading of papers in sectional meetings
- 4:00 P M —Invitation address on "The Evolution of the Grand Canyon Region," by Dr Douglas Johnson, of Columbia University, New York City
- 6:30 P M —Annual banquet at the New Neil House
- 8:00 P M —The Presidential Address on "The Social Significance of Science," by President Rea

SATURDAY, APRIL 10

- 8:00 A M —Adjourned business meeting
- 9:00 A M —Reading of papers in general session, including two very interesting symposia, one on "Animal Parasitism" and the other on "Biological Training for Medicine and Dentistry "

MINUTES OF THE BUSINESS MEETINGS

The first business session was called to order by President Rea at 9 05 A M , Friday, April 9, 1926, in the Auditorium of the Archaeological Museum

The President announced the appointment of the following committees

Committee on Membership—M E Stickney, W M Barrows,
J Ernest Carman

Committee on Resolutions—Edward L Rice, F C Waite,
E L Moseley

Committee on Necrology—Henry C Beardslee, Herbert
Osborn

The following *Auditing Committee* was then elected by the Academy Raymond C Osburn, David Dietz

The following *Nominating Committee* was elected by ballot by the Academy Herbert Osborn, M E Stickney, J Ernest Carman, F C Waite, H E Burt, and F C Blake

The reports of the following officers and standing committees were called for, read and ordered filed, viz The Secretary, the Treasurer, the Executive Committee, the Publications Committee, the Trustees of the Research Fund, the Library Committee and the Committee on State Parks and Conservation

At an adjourned meeting held in Room No 100, Botany and Zoology Building, 8 00 A M , Saturday, April 10, the reports of the special committees, namely, the Committee on Membership, on Resolutions, on Necrology, on Legislation, on Auditing, and on Nominations, were read, approved and ordered filed The reports of all committees, standing and special, together with the officers' reports, are published in full below

Under the head of new business, Dr Edward L Rice requested the prompt and cordial co-operation of the members of the Academy in bringing to his attention all instances of adverse or unfriendly legislation, actual or proposed, regarding the teaching of science in the public schools and educational institutions of the country Doctor Rice is the official representative of the Ohio Academy of Science in the American Association for the Advancement of Science in matters along the line of his request

The business meeting was adjourned at 8.58 a. m.

REPORTS

Report of the Secretary

COLUMBUS, OHIO, April 9, 1926

To the Ohio Academy of Science

Passing the year now ending in hasty review, omitting of course the numerous details that engage the time and attention of the Secretary in the course of the year, we note that the first event of more than passing interest and importance was the holding of memorial exercises in University Hall, Ohio State University, in honor of the late Thomas Corwin Mendenhall, a distinguished member of this Academy, on the afternoon of April 16, 1925. The following was the brief, simple program

PROGRAM

DR WILLIAM OXLEY THOMPSON, *Presiding*

Address by DR IRA N HOLLIS, President of Worcester Polytechnic Institute, Worcester, Mass

Address by DR CHARLES FREDERICK MARVIN, Chief, U S Weather Bureau, Washington, D C

Personal Reminiscences from DR ELIHU THOMPSON, Director of the Thompson Laboratory, General Electric Company, Lynn, Mass

Presentation by the Mendenhall family of a bronze replica of the portrait medallion of Dr Mendenhall given him by his first group of students on the fiftieth anniversary of the opening of the University, September 17, 1923

The following account of these exercises was prepared by Dr A D Cole, of the Ohio State University, who served as the chairman of the committee that arranged the memorial services

"On April 16, 1925, the trustees of the Ohio State University held memorial exercises in honor of Thomas Corwin Mendenhall, the first professor of physics of the University and since 1919 a member of the Board of Trustees. President William Oxley Thompson presided at these exercises. The program included an address by Dr Ira N Hollis, President of Worcester Polytechnic Institute, and an address by Dr Charles Frederick Marvin, Chief of the U S Weather Bureau, Washington, D C. Personal reminiscences by Dr Elihu Thompson, Director of the Research Laboratory, General Electric Co., and by Dr Edward S Morse, President of the Lynn, Mass., Peabody Academy of Science, Salem, Mass., were read.

Dr Hollis spoke of Dr Mendenhall's service to the Worcester Polytechnic Institute as its president from 1894-1901, which included the successful establishment of important changes in its educational policy. He emphasized Dr Mendenhall's fine spirit of co-operation with other forward-looking men as effective in the accomplishing of needed reforms.

Dr Marvin spoke sympathetically of Dr Mendenhall's early work in organizing the scientific work of the then new Ohio State University and interesting the Columbus public in all the important scientific discoveries of the time. Dr Marvin also showed how his effectiveness as a scientist

was greater because "he acted and moved in an atmosphere of warm human affection, sympathy, good fellowship and sunshine." An interesting personal touch was added when he told of his own experiences as assistant to Dr Mendenhall in experiments for the Lowell lectures of 1882 in Boston and in organizing the research work of the Signal Corps of the U S Army at Washington a little later. He gave an interesting account of Dr Mendenhall's important improvements in the accurate measurements of length and time which form an important part of the work of the U S Coast and Geodetic Survey, of which he was Superintendent from 1889 to 1894.

Dr Elihu Thompson told how Dr Mendenhall had conducted the first efficiency tests of commercial electric lighting ever made in this country (at Cincinnati in 1883), also of his important activities in the International Electrical Congress in 1893, which adopted definitions for the ampere, volt and other electrical units.

Dr Edward S Morse confined his memories largely to their joint labors as professors in the Imperial University of Japan, where they were very intimately associated and very close friends. He gave a fine tribute to Dr Mendenhall as a teacher and scientist, with special emphasis upon his extraordinary personal charm.

President Thompson made two interesting announcements. The first that the Trustees of the University had named the large Physics Building the Mendenhall Laboratory in recognition of his important services to the institution, both as professor of physics for many years and as a member and chairman of its Board of Trustees. The second announcement was that his son, Professor Charles E Mendenhall, of the University of Wisconsin, had given to the University a replica of the beautiful bronze medallion portrait of Dr Mendenhall which was presented to him by the surviving members of that first group of seventeen students, on the 50th anniversary of their enrollment when the University opened its doors in September, 1873.

Professor Charles Mendenhall was present with his wife and son. They and the two principal speakers were later guests of the Faculty Club at a banquet given to them and the University Trustees in the Club dining room."

Certificates of election to fellowship in the Academy were sent to all those elected at the Wooster meeting, on April 3, 1925.

A brief report of the Thirty-fifth Annual Meeting of the Academy was prepared and sent to *Science*, and was published in that journal of July 17, 1925, pages 60-62, (Vol LXII, No 1594, New Series).

The Secretary represented the Academy in the Council of the American Association for the Advancement of Science at the Kansas City meeting, December 29, 1925, to January 3, 1926. Perhaps attention should again be called to the fact that the Council of the A A A S at the Kansas City meeting passed a special ruling by which any member of an affiliated society or academy may join the Association without the payment of the usual \$5.00 entrance fee. It was also noted with considerable pride and pleasure that one of if not the outstanding address of the meeting was made by one of our own members, namely, Dr Dayton C Miller, of the Case School of Applied Sciences, Cleveland,

Ohio Doctor Miller gave that great gathering of scientists an unusual thrill when he announced that as a result of more than one hundred thousand separate readings or observations on ether drift, performed under the most trying circumstances in 1925, that it has been determined in effect that the earth does drag the ether so that the apparent relative motion at the point of observation is one-twentieth of the absolute motion and that the earth and the whole solar system are rushing headlong into the dragon of the sky, the constellation Draco, at the immense speed of at least 125 miles per second, perhaps faster'

On March 19, 1926, the Secretary received a telegraphic request from Watson Davis, editor, *Science Service*, for copies or abstracts of the papers to be presented at this meeting in order to send out some ten days in advance of the meeting news stories regarding the principal papers to be read. This request could not be complied with, as copies and abstracts were not available. Given as a hint for the future'

Respectfully submitted,

WM H ALEXANDER, Secretary

Report of the Treasurer for the Year 1925-1926

The following report from the Treasurer was received and referred to the Auditing Committee for examination. The report of the Auditing Committee is appended.

To the Ohio Academy of Science

Your Treasurer submits the following report for the period from March 13, 1925, to April 1, 1926, inclusive.

RECEIPTS

Cash balance as of March 13, 1925	\$ 961 01
Interest total on certificate of deposit payable in two checks of April and October	39 00
Library sales of publications	37 74
Received from Secretary A A A S allowance of fifty cents per member of the A A A S on 207 members, 1926 collections to date	103 50
From Academy members' accounts to date	592 20
Total Receipts—Exhibit A	\$1,733 45

DISBURSEMENTS

To Wm H Alexander, Secretary's honorarium	\$ 100 00
To The Ohio Journal of Science for 1925 subscriptions	372 00
To Postmaster, Columbus Post Office, for stamped envelopes	21 92
To Postmaster, Columbus Post Office, for stamps	10 00
To A E Kraus Print Shop	79 75
To Hiss Stamp Company	80
To Helen Coleman, stenographic assistance	8 00
To Wm H Alexander, secretarial expenses	14 54
To B E Livingston, forwarded dues	6 00
To check returned—account closed	2 00
To R A Hefner, check for incorrect payment A A A S dues	4 00
To Wm H Alexander, secretarial expenses	2 36
To the Ohio Journal of Science for 1926 subscriptions	396 00

Total Disbursements—Exhibit B

\$1,017 37

BALANCE SHEET

Exhibit A—Receipts	\$1,783 45
Exhibit B—Disbursements	1,017 37

Cash balance on hand April 1, 1926 \$ 716 08

Estimated current liabilities including expenses of the meeting and printing and the 1926 Secretary's honorarium would amount to approximately three hundred dollars, leaving an available surplus of approximately four hundred dollars

Respectfully submitted,

A E WALLER, *Treasurer*

Report of the Auditing Committee

COLUMBUS, OHIO, April 10, 1926

The Auditing Committee of the Ohio Academy of Science at its Annual Meeting, April 10, 1926, has examined the books of the Treasurer of the Academy and of the Trustees of the Research Fund of the Academy and find them to be correct

(Signed) RAYMOND C OSBURN,

DAVID DIETZ,

Auditing Committee

Report of the Executive Committee

COLUMBUS, OHIO, April 9, 1926

To the Ohio Academy of Science

Pursuant to a call of the President, the Executive Committee met at the office of the Secretary, 16 East Broad Street, Columbus, January 9, 1926, with all members present and in addition Dr C H Kennedy, Vice-President of the Zoology Section. President Rea called the meeting to order at 2 10 p m, and after a brief statement by the President of the purpose of the meeting and a short general report by the Secretary as to routine matters during the year, the following motions were made and agreed to, viz

That the Academy be asked at its next annual meeting to pass a resolution authorizing the Executive Committee, in worthy cases and at its own discretion, to relieve members of 20 years' or more standing of further payment of dues

That a letter be written by the Secretary to Mr Otto H Swezey expressing the regrets of this Committee that he has severed his connection with the Academy

That the Secretary prepare the draft of a revision of Article III, Membership, of the Constitution so as to eliminate the class of members known as "Corresponding Members" and present same at the next annual meeting of the Academy

That the Treasurer be requested to secure from the Librarian of the Ohio State University an inventory of all Academy publications now on hand and, if possible, make some definite agreement as to the sale and distribution of same

That the Vice-Presidents of the several sections be the accredited representatives of the sections to the A. A. A. S. and in the event the Vice-President of a section cannot attend, he appoint a representative

That the next annual meeting of the Academy be held at the Ohio State University, Columbus, as per standing invitation, on April 9 and 10, 1926.

The applications for membership in the Academy of Mr Warren C Miller, Bedford, Ohio, and Mr Francis J Pettijohn, Oberlin, Ohio, were favorably acted upon, subject to ratification by the Academy

A second meeting of the committee was held last evening at the office of the Secretary, at which the following items of business were agreed upon, viz

That the Publications Committee be requested to arrange for the printing of a revised list of the publications of the Academy, that 500 reprints of said list be made for the use of the Library Committee, and that the advisability of reprinting some of the older publications, the supply of which has become exhausted, be taken up

That the Academy be asked to send its Treasurer, Dr A E Waller, as the official representative to the International Botanical Congress to assemble at Ithaca, N Y, in August, 1926, and that the Academy pay his actual transportation expenses to and from the meeting

That the applications of the 51 persons for membership in the Academy, presented by the Secretary, be approved subject to ratification by the Academy

Dr Frederick H Krecker, editor of THE OHIO JOURNAL OF SCIENCE, came before the committee and made a full frank statement regarding the OHIO JOURNAL OF SCIENCE—its financial needs, desired improvements, policies, changes, actual and proposed, etc In line with the suggestions of Doctor Krecker it was voted unanimously to recommend to the Academy that the retiring President and the President be made the representatives of the Academy on the Editorial Board of the Journal and that the Academy express its entire approval of the efforts and plans of the Editorial Board to improve the Journal and pledge its support in any proper effort to secure additional financial support To this end, the Committee suggests that the Executive Committee for the ensuing year be requested to consider fully the whole matter and if thought advisable, recommend some plan by which the Academy may extend additional financial support to the JOURNAL

Respectfully submitted,

WM H ALEXANDER, *Secretary*

Proposed Amendment of the Constitution

(By the Executive Committee)

That ARTICLE III—*Membership*, be amended to read as follows

ARTICLE III —MEMBERSHIP

1 *Classes of Members* —The Academy shall be composed of members, fellows, honorary members and patrons

2 *Members* —Members shall be persons interested in scientific work

3 *Fellows* —Fellows shall be persons who are engaged in productive scientific work

4 *Honorary Members* —Honorary members shall be persons distinguished for their attainments in science and not resident of the State of Ohio Their number shall not exceed twenty-five

5 *Patrons* —Patrons shall be persons who have bestowed important favors upon the Academy as defined in the By Laws

6 *Privileges of Members* —Only members, fellows and patrons shall be entitled to vote in the Academy, only fellows and patrons shall be eligible to office and to membership in the Executive Committee

And further, that such other verbal changes as may be necessary to make the Constitution and the By-Laws consistent with the foregoing be made

Report of the Trustees of the Research Fund

The Trustees of the Research Fund, in presenting a financial statement of the condition of the funds in hand, desire to call attention to the action at our last meeting authorizing the allotment of funds in assistance of scientific investigations and the use of the income from \$1,000 of invested funds to be known as the McMillin Grant, in recognition of an exceptional contribution to science by a member of the Academy. The Trustees have not received any nominations for such an award this year, but will be pleased to have nominations during the coming year.

A request for an allowance to aid in the publication of a paper by Dr W M Barrows was granted.

The balance on hand at the time of the report of a year ago was \$1,362 91, of which \$1,300 was invested in bonds and the interest added during the year, \$91, giving a total of \$1,453 91, less the grant to Dr Barrows of \$70, gives a present total of \$1,383 91, or a cash balance of \$83 91 above the \$1,300 00 invested. Interest accruing April 15th will give an available balance of \$127 41 for grants during the coming half year without drawing upon the invested fund. An additional \$45 50 will be due October 15th.

Unless it is the wish of the Academy that the fund be allowed to accumulate, we will be pleased to receive requests for the use of the available balance, although it is obvious that no large sums can be allotted. Vouchers, bank statement and receipt for bonds deposited will be furnished the auditing committee.

Respectfully submitted,

HERBERT OSBORN, *Chairman*,
EDWARD L RICE,
GEO D HUBBARD,

Columbus, Ohio, April 10, 1926

Trustees

Report of Committee on State Parks and Conservation

A meeting was held at the Neil House, Columbus, evening of April 8th, 1926, and the committee begs to report progress and certain recommendations for consideration.

According to statements of State Forester, Mr Secrest, there have been additions to the state forests which bring the total to 19,826 acres, at an average cost of \$6 10 per acre, and further additions are being made so that progress in this field is encouraging.

Recent legislation concerning sanitary regulations for state parks as set forth in bulletins and leaflets from the State Department of Health have provided for the control of parks in this respect in a very efficient manner. A general and whole-hearted compliance with these regulations will ensure healthful conditions for all those who use the parks.

A start has been made in the organization of an advisory Council on State Parks and Conservation by the calling of a conference by the Director of Agriculture which was attended by representatives from this committee, the Board of Agriculture, Board of Health, Federation of Women's Clubs, the Geological Survey and Sportsmen's League and other organizations, and such a council was considered as a very desirable organization. It is hoped that the organization may be consummated in the near future.

The Naturalists Guide, mentioned in previous reports as in preparation, has recently been issued and no doubt many of our members are already familiar with its contents. It must serve a very useful purpose and additions to the localities listed for Ohio may very properly be presented to this committee or to the Academy through the Ohio Journal of Science.

Reports from different members indicate that there is great need of prompt action to preserve the natural beauty and native condition of some of our state owned tracts. Some places recently made accessible to autoists are reported to be sadly misused and their natural beauty despoiled by the ruthless destruction of shrubs, vines and small trees, which are essential not only to the beauty and scenic attractiveness of the parks, but an essential factor in the preservation of birds and other animals. Definite rules as to use of the park areas and restrictions placed on those who visit them appear to be the only way to prevent such vandalism, but we believe every effort should be made to secure the voluntary compliance with the necessary regulations by the education of the public in the proper use of such state property.

The following recommendations, offered by the Committee on State Parks and Conservation, were unanimously adopted by the Ohio Academy in annual meeting at Columbus, Ohio, April 9, 1926.

- 1 That we express our appreciation of the progress made in the acquisition of State Forests and Game Refuges and the hope that these may be largely increased in number and extent.

- 2 That we approve the sanitary regulations for State Parks adopted by the State Department of Health and urge the most cordial and universal support in their enforcement and their extension to other sites.

- 3 That we heartily approve the organization of an advisory council on State Parks and Conservation, to consist of representatives from the State departments, institutions and societies interested, to consider and advise regarding the best measures for the preservation of the natural features, wild life and the historic and scenic beauties in tracts that are owned or controlled by the State.

- 4 That we especially urge wherever practicable the setting aside of certain parts of the State Forests and Game Refuges, or other tracts under State control as wild life sanctuaries or preserves, with a view to the permanent preservation of the native associations of plants and animals so that they may serve our own and future generations as examples of the primitive fauna and flora of the State. Where camp sites are allowed these should be restricted to a definite small area and supervised.

- 5 That we encourage the widest publicity and educational effort to acquaint the public with the need of universal observance of measures to protect from injury or destruction by digging, uprooting, cutting, blazing, mutilation, fire or other means, the wild flowers, shrubs, trees and natural conditions essential to the beauty of the parks and the survival of both plant and animal representatives of our native forms of life.

6 We urge the posting of suitable placards throughout the park areas or reserves to inform all persons as to regulations for the preservation of all wild life

7 That we urge a wider attention to studies of the native plants and animals on the part of teachers in the public schools and the support of the Audubon societies and the Wild Flower Preservation societies in their laudable efforts to educate the people of the country to a better knowledge of the dangers of extinction for many of our most interesting forms of life

8 That copies of these recommendations be forwarded by the Secretary to the State departments, institutions and societies known to be interested

HERBERT OSBORN, *Chairman*,

E L FULLMER, E N TRANSEAU,

E LUCY BRAUN, A R HARPER,

E R HAYHURST, EDMUND SECREST,

C G SEATZER, BRUCE FINK

(The last three—Harper, Secrest and Fink—did not see the above recommendations before they were read and adopted)

Discussion

Following the reading of the foregoing report, Doctor Transeau, Ohio State University, called attention to the damage being done at Old Man's Cave, by way of emphasizing the importance of the eighth recommendation requiring the Secretary to send copies of the recommendations "to the State departments, institutions and societies known to be interested" Miss E Lucy Braun, University of Cincinnati, expressed the opinion "that while a letter from the Secretary of the Ohio Academy of Science with these recommendations would be of interest, it would merely be set aside. It should be followed up by the recipient by writing to State officials, who will thus learn that the people of the State know about and are interested in and pushing conservation movements."

Report of the Library Committee

April 8, 1926

To the Ohio Academy of Science

The Library Committee wishes to call the attention of the Academy to the very healthy growth of its exchange list during the past twelve years under the able custodianship of Mr Reeder, which ended last year, and it desires to convey to Mr Reeder the thanks of the Academy for his long-continued and unselfish services, and to express its regret at the severance of the relation

In 1909 Professor Mills, who was then Librarian of the Academy, reported seventeen institutions on the Academy's exchange list. In 1914 the Academy entered into an agreement with the Ohio State University Library concerning the deposit of the library of the Academy with the University Library. Early in 1915 this deposit was made, and the Academy Library and exchanges came under the immediate care of

Mr Reeder At the 1920 meeting, Mr Reeder reported "Sixty-five institutions on the exchange list " In 1921 there were sixty-eight In 1922 his report read "seventy-one institutions on the exchange list," while at the 1925 meeting he stated "some additions have been made to the list this year "

In nearly every report which Mr Reeder has made since 1915 he has emphasized the desire of the University Library to serve the Members of the Academy with scientific literature for their research, and its willingness to lend to any member, through his institutional library, any publication needed in research work He has expressed the hope that more members of the Academy would take advantage of this opportunity so that "more and more the University Library would serve as the center of scholarly research by members of the Academy "

In 1920 he reported loans made by the University Library of only forty-two books to nine Ohio Colleges It seems to the Committee that a much larger use of the facilities of the University Library should be made by the members of the Academy Such use of the University Library by members of the Academy is open to them not merely as a courtesy of the University, but as their right under Articles 8 and 9 of the "Agreement Between the Ohio Academy of Science and the State University Library," entered into in 1914

Since Mr Reeder's resignation early in 1925 the care of the Academy exchanges has been largely in the hands of Miss McKee, of the University Library Staff, who has been too burdened with other duties to give them adequate attention Recently, however, Mrs Ethel M Miller, librarian of the departments of Botany and Zoology, has been assigned by the University to take charge of the exchanges of both the Academy and the Ohio Journal of Science She is entering upon her work with enthusiasm and in a very methodical and business-like way The Academy is to be congratulated upon having its exchanges in such able hands

The Committee wishes to call the attention of the Academy to several points, where the University Library seems to have failed in its handling of the Academy exchanges

1 Under Article (5) of the Agreement of 1914, "The University Library agrees to keep a Separate Card Catalogue of the library of the Academy, showing the accession records " While under Article (1) the Academy library is defined as "its collection of books, pamphlets, periodicals and other publications, now constituting its library, together with future additions "

This Separate Card Catalogue does not appear to have been maintained It seems especially desirable that the Academy should possess such a record of its original library and accessions

2 In 1917 the Academy voted "that a suitable printed plate, to be paid for by the Academy, be put in the books given to the Ohio State University Library " This plate seems not to have been placed in any of the accessions to the Academy library received by exchange since 1917 The Committee feels that this failure should be rectified

3 A clear cut separation of accessions to the University Library through purchase, through gift and through exchange of Academy Proceedings and Papers, of the Ohio Journal of Science and of the Ohio Biological Survey publications does not seem to have been maintained So that in many cases proper credit has not been given for the accessions For example, certain accessions have been

credited in one place to the Academy and in another place to Purchase. It may be impossible, therefore, to determine at this time, with any degree of accuracy, what accessions have been received through the Academy exchanges. This should be investigated and remedied so far as possible.

The Committee finds that the price list of its Proceedings and Special Papers is practically exhausted. It suggests that the list be brought down to date, that it be published each year with the Annual Report as an advertising page, and that extra copies of the list be issued for the use of the Librarian in answering inquiries. Certain Special Papers are nearing exhaustion. The Committee advises their republication.

The Committee wishes also to submit the accompanying report of Miss McKee, of the University Library Staff, who has had charge during the past year of the sale and distribution of the Academy publications. For purposes of accurate record it is to be noted that the \$28.15 referred to by Miss McKee as turned over to the Treasurer of the Academy is made up of two items, viz, \$25.53 from the sale of publications during the year, and \$2.62, referred to in the last report as outstanding from the sales of 1924, but collected since then.

Respectfully submitted,

FREDERICK O GROVER, *Chairman*

Report of Miss McKee for the Ohio State University Library

To the Ohio Academy of Science

The University Library received in 1916 a deposit of the Ohio Academy of Science containing a number of exchanges, many of them foreign periodicals. At that time a campaign for additional exchanges was undertaken with the result of about two hundred new titles.

In 1921 letters were again sent out in another attempt for additional exchanges, but results were not so satisfactory. Since that time owing to the rapid increase in the number of students making new demands on the library without a corresponding increase in the Staff, it has been impossible to undertake any systematic effort for new exchanges, although some new ones have been added to the list.

During the past year an attempt has been made to reorganize the records of Academy material in the library and a card record is being established in the Botany and Zoology department library. This record will consist of the titles deposited by the Academy in 1916 with the additional titles added by exchanges established since that time. It will not be a complete record of volumes and numbers to date, as this would duplicate work already being done at the main library, but will give a working list of titles available.

We hope by the next meeting to be able to report to the Academy as to the exact number of volumes and the approximate money value of your exchanges.

An inventory has been taken of the numbers of Special Papers and Proceedings of annual meetings in stock, which is appended. By this it will be seen that numbers 13 and 15 are entirely out of print.

The price list of Special Papers and Proceedings is decidedly out of date and as the supply is low, it might be wise to have a new edition of this list, especially if a campaign for exchanges is to be instituted

The sale of Special Papers and Proceedings has gone on as usual during the year, amounting to \$28 15, which has been turned over to the Treasurer of the Academy

Proceedings of the 35th annual meeting were received in August and mailed out to the members as soon after that as possible, although we regret that there was some delay in this mailing owing to vacations and illness in the Library Staff

One of the most valuable tools for the research worker which has issued lately is the "Union List of Serials in the Libraries of the U S and Canada " This compilation is the result of co-operation among the libraries of the two countries and is being published by the H W Wilson Co, of New York Each co-operating library receives first a checking list in which it states the periodicals regularly received, and, later a completed list, giving the name of each library receiving a given title regularly The work has proceeded through the letter R and the completed volumes should be available next year Already this has proved itself to fill a long felt need

Work on the filing of cards in the depository catalog of the Library of Congress is progressing, although it is not yet in shape for use When this is available the Library will have in this and the Union List two of the most valuable tools possible for inter-library loans of which Academy members may avail themselves.

(Signed) ALICE D McKFE,
For Ohio State University Library

Inventory of Special Papers, Proceedings Etc , of Ohio Academy of Science, April 1, 1906, in Stock and Deposited with the Ohio State University Library

CONSTITUTION AND LIST OF MEMBERS

135 copies

SPECIAL PAPERS

1	188 copies	8	90 copies	15	0 copies
2	120 copies	9	180 copies	16	186 copies
3	164 copies	10	225 copies	17	288 copies
4	125 copies	11	256 copies	18	198 copies
5	69 copies	12	185 copies	19	199 copies
6	125 copies	13	0 copies		
7	242 copies	14	262 copies		

REPORTS AND PROCEEDINGS

1	89 copies	13	230 copies	25	194 copies
2	134 copies	14	245 copies	26	152 copies
3	176 copies	15	231 copies	27	163 copies
4	212 copies	16	218 copies	28	149 copies
5	182 copies	17	238 copies	29	118 copies
6	189 copies	18.	never published	30	128 copies
7	268 copies	19	560 copies	31	50 copies
8	215 copies	20	180 copies	32	352 copies
9	260 copies	21	219 copies	33	294 copies
10	220 copies	22	207 copies	34	303 copies
11	240 copies	23	194 copies	35	282 copies
12	265 copies	24	209 copies		

Report of the Committee on Legislation

April 9, 1926

To the Ohio Academy of Science

Your Special Committee on Legislation has been rather inactive during the year just closing, not a single formal meeting of the committee having been held. However, there has been some informal conferences and correspondence among the committee members and the prevailing opinion seemed to be that there was little that could be done at this time. Furthermore, the committee feels that before a renewal of effort before the General Assembly in behalf of any bill is made that the Academy should definitely decide whether or not it really wants to surrender its present informal and independent form for that of a state-supported institution, and if so, then action should be taken to work out a more careful program of the broad services it hopes to render the State before the question of legislation is taken up anew. If anything is to be accomplished in the future along these lines it will be necessary for the Academy first to sell the proposition to itself and then by a united, enthusiastic effort present a proposal of such evident, unquestioned merit that it will sell itself to the General Assembly and the Governor.

Respectfully submitted,

WM H ALEXANDER, *Chairman*,
M M METCALF, EDW L RICE,
PAUL M REA, L B WALTON

Report of Committee on Election of Fellows

COLUMBUS, OHIO, April 9, 1926

To the Ohio Academy of Science

A meeting of the Committee on the Election of Fellows was held last evening at the office of the Secretary, 16 East Broad Street, Columbus, with a quorum present. Of the candidates considered, five received the necessary favorable votes and were declared elected. The Fellows elected will be personally notified, and the list published in the Proceedings of this meeting.

Respectfully submitted,

WILLIAM H ALEXANDER,
Secretary, for the Committee

The following is a list of those elected Fellows

J H GOURLEY, Wooster
NELLIE F HENDERSON, Columbus
ONDESS L INMAN, Yellow Springs.
HARRY M JOHNSON, Columbus.
H C YOUNG, Wooster

Report of the Membership Committee

To the Ohio Academy of Science

Applications in due form have been received from the following persons and we recommend their election to full membership in the Academy, effective upon the payment of one year's dues, viz

ACKERMAN, LLOYD, Western Reserve University, Cleveland
 ARNOLD, H J, Wittenberg College, Springfield
 BAKER, (Miss) MARGARET, Otterbein College, Cochran Hall, Westerville
 BEHRE, CHARLES H, JR, University of Cincinnati, Cincinnati
 BERRY, FRED, State Department of Health, O S U, Columbus
 BLOCHER, JOHN M, 379 Beech Street, Berea
 BODENBERG, EMMETT T, Capital University, Columbus
 BOESSEL, M W, Botany and Zoology Bldg, O S U, Columbus
 BORST, HAROLD L, Farm Crops Dept, O S U, Columbus
 BROWN, HELEN J, 55 Kelso Road, Columbus
 CASSIDY, HAROLD, 216 S Maple Street, Akron
 CHAFFARS, M E, Miami University Oxford
 DUNFORD RALPH E, Dept of Psychology, O S U, Columbus
 EDGERTON, HAROLD A, Dept of Psychology O S U, Columbus
 ELIOT, THEODORE SESSINGHAUS, 2109 Adelbert Road Cleveland
 ELLIOTT, RUSH, Box 421, Athens
 EYE, L F, Dept of Health, O S U, Columbus
 FISHER, MILDRED, 2594 Summit St Columbus
 FORDYCE, GEORGE L, 40 Lincoln Ave, Youngstown
 FRANKS, ROSCOE W, 80 W Eighth Ave, Columbus
 FRAYNE, J G, Antioch College, Yellow Springs
 FREY, CARL A, 16 President St, Athens
 GILMORE, R CLARK, Bot Dept, O S U, Columbus
 HATHAWAY, S R, 3 Van Vorhes St, Athens
 HAZARD, FRANK O, Wilmington College, Wilmington
 HOSKINS, J HOBART, Dept of Botany, University of Cincinnati, Cincinnati
 HURST, MACLEOD E, Orton Hall, O S U, Columbus
 HUTTER, HARRY K, 1222 Stewart Ave, Cambridge
 JOHNSON, MINNIE M, 312 W Ninth Avenue, Columbus
 JOHNSTON, WILLIAM DRUMMON, JR, Dept of Geology, University of Cincinnati, Cincinnati
 JONES, H LEE, Antioch College, Yellow Springs
 KAUTZ, H W, 4612 Glenshade Ave, Cincinnati
 KEELER, ALMA, 377 W Ninth Ave, Columbus
 KINDER, DR D J, 1442 Neil Ave, Columbus
 KUECHLE, THEODORE FRED, 1180 Wyandotte Road, Columbus
 MAXFIELD, FRANCIS N, Dept of Psychology, O S U, Columbus
 MILLER, VERNON L, Dept of Psychology, O S U Columbus
 MILLER, WARREN C, Bedford High School, Bedford
 MITCHELL, ROBERT H, St Clairsville
 MOORE, ROBERT A, Hamilton Hall, O S U, Columbus
 PETLAY, FRED, New Concord
 PETTIJOHN, FRANCIS J, 136 Woodland Ave, Columbus
 PFLEIDERER, E R, Dept of Psychology, O S U Columbus
 PHILLIPS, JAMES McIVOR, 1963 Iuka Ave, Columbus
 PRATT, KARL C, Dept of Psychology, O S U, Columbus
 RENSCHAW, SAMUEL, Dept of Psychology, O S U, Columbus
 REKROAD, CARL N, Dept of Psychology, O S U, Columbus
 REYMERT, MARTIN L, Wittenberg College, Springfield
 ROLLAND, WILLIAM A, 2419 Pomeroy St, Columbus
 ROOSE, ROBERT L, 16 Lloyd St, Barborton
 SANDS, OLIVE RUTH, 80 Clinton Heights Ave, Columbus
 SEASHORE, ROBERT H, Dept of Psychology, O S U, Columbus
 SEBERT, (Mrs) NORMA, College of Medicine, O S U, Columbus

SHAW, MARGARET F, 312 W Ninth Ave, Columbus
 SMITH, CLAYTON S, Hamilton Hall, O S U, Columbus
 SOUTH, EARL B, Dept of Psychology, O S U, Columbus
 SPIEKER, EDMUND M, Orton Hall O S U, Columbus
 STOUT, GILBERT LEONIDAS, Dept of Botany, Miami University Oxford (Home Address) R No 5, Lockland, Ohio
 THUT, HIRAM F, 1501 Neil Ave, Columbus
 TRAUTMAN, MILTON B, 618 S Fifth St, Columbus
 TRYON, MARGARET E, Otterbein College, Cochran Hall, Westerville
 TURNER, JEAN, 80 W College Ave, Westerville
 VALENTINE, WILLARD L, Ohio Wesleyan University, Delaware
 VISSCHER, J PAUL, Western Reserve University, Cleveland
 WILLIAMS, PEARLE E, Botany Dept, O S U, Columbus
 WILSON, ORVILLE TURNER, University of Cincinnati, Cincinnati
 WILSON, WILLIAM R, Dept of Psychology O S U, Columbus
 WINNETTE CLIFFORD L, 66 East Main St, New Concord
 WRIGHT, FRANK J, Granville

Respectfully submitted,

M E STICKNEY, *Chairman*,
 W M BARROWS,
 J ERNEST CARMAN

Report unanimously approved

Report of Nominating Committee

President—WILLIAM MCPHERSON, Ohio State University, Columbus

Vice-Presidents

Zoology—JAMES A NELSON, Mt Vernon

Botany—N M BENEDICT, University of Cincinnati, Cincinnati

Geology—WILBUR E STOUT, Ohio State University, Columbus

Medical Sciences—EMERY R HAYHURST, Ohio State University, Columbus

Psychology—GARRY C MYERS, Cleveland School of Education, Cleveland

Physical Sciences—CHARLES H SKINNER, Ohio Wesleyan University, Delaware

Secretary—WILLIAM H ALEXANDER, U S Weather Bureau, Columbus

Treasurer—A E WALLER, Ohio State University, Columbus

Elective Members of Executive Committee—C G SHATZER, Springfield, and ALPHEUS W SMITH, Columbus

Publications Committee—H C SAMPSON, Ohio State University, Columbus

Trustee Research Fund—HERBERT OSBORN, Ohio State University, Columbus

Library Committee—F O GROVER, Oberlin College, Oberlin

Committee on State Parks—BRUCE FINK, Oxford, E R HAYHURST, Columbus, and E N TRANSEAU, Columbus

Respectfully submitted,

HERBERT OSBORN, *Chairman*, F C WAITE,
 M E STICKNEY, H E BURTT,
 J ERNEST CARMAN, F C BLAKE

The report was unanimously adopted and the above named persons duly elected to the positions indicated By a previous

action of the Academy, the new President, Dr Wm McPherson, and the retiring President, Dr Paul M Rea, become the Academy representatives on the Editorial Board of the OHIO JOURNAL OF SCIENCE

Report of the Committee on Necrology

COLUMBUS, OHIO, April 10, 1926

To the Ohio Academy of Science

The Academy has suffered the loss by death of three of its members during the year just ended, namely, Harry Arthur Gossard, Wooster, Ohio, Henry Curwen Lord, Columbus, Ohio, and Roscoe J Webb, Garrettsville, Ohio. The following brief notes on the life and work of these esteemed members are presented for your information.

I HARRY ARTHUR GOSSARD

Prof Harry A Gossard was born on a farm near Ames, Iowa, February 7, 1868, and died at his home in Wooster, Ohio, December 18, 1925. He entered the Iowa State College in 1886 and graduated with honor in 1889. After graduation he was appointed Assistant in Entomology in the Iowa Experiment Station and carried graduate work in the college, receiving his Master's degree in 1892. He served as President of Albion Seminary at Albion, Iowa, 1893 to 1895, and as instructor in natural sciences in the high schools of Rochester, Minn. and Princeton, Ill. from 1895 to 1898, when he was elected Professor of Entomology, Zoology and Geology and Entomologist of the Experiment Station of Florida. He held this position until 1904, when he was selected to fill the position of Entomologist in the Ohio Experiment Station, where he remained until his death.

Prof Gossard's work was characterized by a very full appreciation of the practical needs of agriculture and horticulture and a very thorough and painstaking method of experiment and investigation. His numerous published papers and the large number of exhaustive studies made by his assistants give abundant evidence of his insight into the basic needs of insect control and the practical applications of scientific results. His worth was recognized in honors from various scientific bodies, one of the most recent being the Presidency of the American Association of Economic Entomologists.

Among his hosts of friends in Ohio and throughout the country he was esteemed as a man of most sterling character, a safe councillor whose judgment always commanded respect and all unite in sincerest sympathy for the bereaved family. In his death the Academy has lost one of its conspicuous contributors to science and the state a conscientious, able administrator in research activity.

II HENRY CURWEN LORD

Prof Henry C Lord was born at Cincinnati, Ohio, on April 17th, 1866, and died at Columbus, Ohio, September 16, 1925. He studied at Ohio State University during the years 1884 to 1887, and received his Bachelor degree from the University of Wisconsin in 1889. He came to the Ohio State University in 1891 first as assistant in Mathematics and Astronomy, and later, 1894, as Associate Professor of Astronomy, and in 1900 Professor of Astronomy and Director of the Emerson McMillin Observatory, a position he held until his death.

Professor Lord was an intense worker and his talents were recognized not only in his particular field, but among scientific workers in many branches. He was interested especially in astrophysics, but had a wide knowledge in various branches of science and was keenly interested in the educational problems connected with university life. Among his colleagues he was noted and greatly respected for his ability to analyze complex situations and to state his opinions in concise and logical terms.

He took part in a number of Eclipse expeditions and one of his notable achievements was the securing of an exceptionally valuable series of photographs during the eclipse of October, 1900. He was a member of a number of scientific societies,

among them the Royal Astronomical Society and the Astronomical and Astrophysical Society of America, and his published papers appear in a number of scientific journals. He became a member of this Academy in 1915 and was made a Fellow in 1920. He was, no doubt, best known among his colleagues at the University and especially to a favored circle of friends and admirers who will always remember him with affection. We desire to record our sincere sympathy for the bereaved family and relatives in their great loss.

III ROSCOE J WEBB

Roscoe J. Webb was born at Garrettsville, Ohio, on May 19, 1875. He completed his high school course in his native village in 1894 and entered Hiram College in the fall of the same year, but was compelled by the frailty of his health to give up college work after a few months.

He studied law in his father's office and was admitted to the bar in 1906. Forming a partnership with his father under the firm name of Webb and Webb, he continued the practice of law with conspicuous success and growing reputation until his death on October 3, 1925.

From early youth Mr. Webb was an ardent lover of nature and pursued the study of the *flora* and *fauna* of his region with great industry and success throughout his life. Few men in the northern part of the State had a wider or more accurate knowledge of our native plants. By his many botanical friends he was known as an authority on the botany of his region.

His life was one of unusual service to his community in which he was a most useful and beloved member. He will be greatly missed by a wide circle of friends to whom his character and scientific attainments had greatly endeared him. He became a member of the Ohio Academy of Science in 1898 and though not a frequent attendant upon its meetings nor personally known to many of our members, his services and contributions to science are well known and much appreciated.

Respectfully submitted,

HERBERT, OSBORN, *Chairman*,
H C BEARDSLEE

Report of the Committee on Resolutions

COLUMBUS, OHIO, April 10, 1926

Resolved,

1. That the Ohio Academy of Science expresses its grateful appreciation of the work of the local committee of the Academy, the officers of the Ohio State University, and the Columbus Chamber of Commerce in arranging so satisfactorily for the success of the meeting and for the comfort and pleasure of the members.

2. That the Academy most heartily thank Dr. Douglas Johnson, of Columbia University, for his extraordinarily interesting and instructive lecture on "The Evolution of the Grand Canyon Region."

3. That the Academy recognizes the benefit to be derived from a more intensive study of the responses of insects and other animals to weather factors, such as temperature, humidity, rainfall and light. It recognizes the need for continuous pure science study along these lines, and endorses the proposal for the establishment of an endowed laboratory for the study of the relations of insects and other animals to weather and climate.

4. That the Ohio Academy of Science, in session at the annual meeting, wishes to voice its protest against the granting of long-time rights and privileges in the grazing lands of the National Forests and other Public Domain. The bill recently introduced by Senator Stanfield (S. 2584) or any other such bill, is directly opposed to all principles of conservation, it threatens the integrity of a national organization, and passes control of public lands to private interests. Control of grazing, or other privilege granted in National Forests and Public Domain, must remain in the hands of a centralized body such as the Forest Service, which can administer all interests.

EDWARD L. RICE, *Chairman*,
F C WAITE,
E L MOSELEY

SCIENTIFIC SESSIONS

The following is the complete scientific program of the meeting

PRESIDENTIAL ADDRESS

The Social Significance of Science

PAUL M REA

PUBLIC LECTURE

The Evolution of the Grand Canyon Region

DOUGLAS JOHNSON

PAPERS

- 1 The Franz Theodore Stone Laboratory (10 min) R C OSBURN
- 2 Science, the Newspaper and the Public (15 min) DAVID DIETZ
- 3 The Crested Butte Region of Colorado (20 min) (lantern),
CLARENCE H KENNEDY
- 4 Effects of Ultra violet Radiation on Inorganic Compounds Enzymes
and Living Organisms (20 min) (lantern) ROBERT C GOWDY
- 5 Some Recent Experiments Bearing on the Problems of Sleep (15 min)
H M JOHNSON AND GEO E WEIGAND
- 6 A Quantitative Life History of Sweet Clover Stand (15 min) (lantern)
O J WILLARD
- 7 A Waterspout on Lake Erie (10 min) (lantern) FREDERICK H KRECKER
- 8 Some Notes on Genetics (10 min) L B WALTON
- 9 The Cost of Quick Shift of Learning Habits (10 min) (lantern),
GARRY C MYERS
- 10 The Corn Borer Invasion of Ohio (20 min) HERBERT OSBORN
- 11 SYMPOSIUM ANIMAL PARASITISM
 - (1) The Past and Future of Medical Parasitology (15 min),
FREDERICK H KRECKER
 - (2) Parasites as Natural Enemies of Insects and the Relatively High
Cost of Artificial Controls (10 min) DWIGHT M DELONG
 - (3) Parasites of Economic Importance in Fish of Ohio (10 min)
RALPH V BANGHAM
 - (4) Notes on the Mallophaga of Ohio Birds (10 min) HAROLD S PETERS
 - (5) Some Interesting Tachinid Parasites of the Gipsy Moth (10 min),
H W ALLEN
- 12 SYMPOSIUM BIOLOGICAL TRAINING FOR MEDICINE AND DENTISTRY
 - (1) Papers by—
DR F L LANDACRE (20 min)
DR FREDERICK C WHITE (20 min)
 - (2) Discussion by—
DR RAYMOND C OSBURN (5 min)
DR EDGAR N TRANSEAU (5 min)
DR EDWARD L RICE (5 min)
DR L B WALTON (5 min)
- 13 Notes on Computing Mean Temperatures for Biological Purposes
(10 min) (lantern) C R CUTRIGHT
- 14 Some Physiological Studies with Hessian Fly (10 min) T H PARKS
- 15 Eugenic Data from Families of College Freshmen (10 min) (Wall
charts) ROBERT A HEFNER
- 16 The Mouthparts and Gonopods of Polyzonum Rosalburn, a Suctorial
Millepede (10 min) (diagrams) STEPHEN R WILLIAMS
- 17 Value of Scientific Work in the Ohio Division of Fish and Game (10 min),
E L WICKLIFF
- 18 Measuring Locomotion and its Variable Components in the Manure
Worm (*a foetida*) (10 min) WM M BARROWS

- 19 Notes on the Ecology of *Goniobasis livescens* (10 min) (wall charts, mounted shells) ROBERT A HEFNER
- 20 Unusual Ohio Faunistic Records Based on Specimens in the State Museum (10 min) JAMES S HINE
- 21 Some Variations in *Drosophila hydei* and *Drosophila funebris* (10 min.), WARREN P SPENCER
- 22 The Range of Tolerance of Three Species of *Euglena* for Hydrogen Ions (10 min) W J KOSTER
- 23 The Origin of the Pleurites in the Insects (10 min) L B WALTON
- 24 Plant Successions in Portage County, Ohio (20 min) (lantern), H C SAMPSON
- 25 Further Notes on the Vegetation of Ohio (20 min) (lantern), E N TRANSEAU
- 26 The Plant Communities of Adams County, Ohio, and Their Relation to the Geological Formation (15 min) E LUCY BRAUN
- 27 Non-dependence of Sexual Stages on Allosomes in Japanese Hop (10 min), J H SCHAFFNER
- 28 Inoculation Experiments with Tomato Streak (15 min) W G STOVER
- 29 Opening of Stomata in Different Wave-lengths of Light (15 min), J D SAYRE
- 30 Ohio Mosses (5 min) NELLIE F HENDERSON
- 31 New and Interesting Fungi for Ohio (20 min) (lantern) H C BEARDSLEE
- 32 The Ohio Puffballs (10 min) MINNIE M JOHNSON
- 33 Some Interesting Fungi Recently Found in Ohio (5 min) W G STOVER
- 34 Siamese Twins of *Arisaema triphyllum* of Opposite Sex Experimentally Induced (5 min) J H SCHAFFNER
- 35 Range of H ion Concentration in Leaves and Stems of Plants (10 min), J D SAYRE
- 36 Fossil Plants from American Coal Balls (15 min) (lantern), J HOBART HOSKINS
- 37 On the Great Number of Seeds Produced by a Single Plant (5 min) EDO CLAASSEN
- 38 Observations on a Species of *Euglena* Frequently Found Growing on a Clay Surface (10 min) E L FULMER
- 39 Seasonal Variation in the Physical Properties of Evergreen Leaves (15 min) (lantern) B S MEYER
- 40 Drainage Changes in Northeastern Washington. (20 min) CARL VER STEEG
- 41 Saw Teeth Forms in Virginia (10 min) GEO D HUBBARD
- 42 Reaction Profiles of Surficial Materials (10 min) G W CONNEY
- 43 Some Shore Line Pot Holes at Half Moon Bay, California (10 min) (lantern) A C SWINNERTON
- 44 A Hamilton Fauna from Northwestern Ohio (10 min) GRACE A STEWART
- 45 The Cynthiana Formation of Kentucky (10 min.) (lantern) PAUL H DUNN
- 46 The Structure of the Siphuncle in Fossil Cephalopods (20 min), AUG F FOERSTE
- 47 Monongahela Formation in Eastern Ohio (5 min.) WILBER STOUT
- 48 Deep Wells of Southern Ohio (5 min) MILDRED FISHER
- 49 Origin of the Natural Brines of Eastern Ohio. (15 min) R C LORD
- 50 Methods of Studying and Correlating Erosion Cycles (10 min), GEO D HUBBARD
- 51 Some Observations on the Validity of the Erosion Levels in Eastern Ohio (20 min) C F MOSES
- 52 Molding Sands Investigated by the Commercial Club of Cincinnati Resource Survey (10 min) (lantern) P WILLARD CRANE
- 53 Notes on Heredity in Man (5 min.) L B WALTON
- 54 Occupational Diseases Reported to the Ohio State Department of Health for the Five-Year Period Ending June 30, 1925 (15 min.), E R HAYEUST AND D J KINDEL
- 55 Transposition of Vessels of the Heart (12 min) R. A MOORE
- 56 Paradoxical Coronary Embolism (12 min) (lantern) ERNEST SCOTT

- 57 Complete Dissecting Aneurysm of the Aorta (12 min (lantern), J E HOBERG)
- 58 A Hitherto Unrecognized Body Function and the System which Operates It (12 min) S G ZINKE
- 59 The Origin and Duration of the Enamel Cuticle (Nasmyth's membrane) (12 min) (lantern) S W CHASE
- 60 The Relation of Hysterectomy to the Oestral Cycle (10 min) E P DURRANT
- 61 Factors Influencing the Oestrous Cycle of the Rat (10 min) M O LEE
- 62 Fatigability of Castrated Rats (10 min) M GANS
- 63 The Differentiation of the Primitive Ectodermal Lines of Amblystoma (10 min) F L LANDACE
- 64 The Interpretation of Recent Studies of the Effects of Insomnia (15 min) H M JOHNSON
- 65 The Beginnings, or Foundation, of Disease, and Their Cause (5 min) S G ZINKE
- 66 Effect of Subcutaneous Injection of Luteal Extract on Cyclic Activity of Female White Rats (5 min) E P DURRANT
- 67 Celloidin injections for the Demonstration of Vascular Pathology, ERNEST SCOTT AND R A MOORE
- 68 Peculiar Perforation of the Intestine ERNEST SCOTT
- 69 The Thyroid Influence on the Behavior of the White Rat (10 min), EDNA RICKEY LOTZ
- 70 Some First Indications of Value of Tests for Learning Nonsense Syllables in School Survey (15 min) FLORENCE MATHER
- 71 Experimental Studies of Certain College Problems (10 min), LUELLA C PRESSEY
- 72 A Philosophical Foundation of Psychology from the Point of View of Phenomenology (15 min) PAUL B MEANS
- 73 The Price of Speed Pressure to the Learner (15 min) (lantern) GARRY C MYERS
- 74 Fundamental Drives and the Doctrine of Sublimation (15 min), H AUSTIN AIKINS
- 75 The Nature of Quality (10 min) R D WILLIAMS
- 76 Mechanism in Psychology (10 min) A P WEISS
- 77 *How the Spectroscope Reveals the Structure of Atoms PROF HENRY G GALE, University of Chicago
- 78 *The Size and Shape of Molecules PROF EDWARD MACK, Ohio State University, Columbus
- 79 *Crystals and Their Structure PROF W J MCCAUGHEY, Ohio State University, Columbus
- 80 †Ultra-violet Filters (10 min) (lantern) ROBERT C GOWDY, University of Cincinnati
- 81 †Some Models of Electronic Phenomena ALPHEUS W SMITH, Ohio State University
- 82 †Measurements of Sound Intensity by Means of a Rayleigh Disk C H SKINNER, Ohio Wesleyan University
83. †Line Absorption Spectra and Their Relation to Energy Levels JOHN G FRAYNE, Antioch College
- 84 †Planetary Nebulae and Stellar Evolution DONALD H MENZEL

* These papers were read before a meeting of the Non Biological Section of the Ohio Educational Conference, to which the members of the Physical Sciences Section of the Ohio Academy of Science were invited

† These papers were read at a joint session of the Physical Sciences Section of the Ohio Academy of Science and the newly-organized Central Ohio Physics Club

DEMONSTRATIONS

- 1 Transposition of Vessels of the Heart R A MOORE
- 2 Celloidin Injections for the Demonstration of Vascular Pathology
ERNEST SCOTT AND R A MOORE
- 3 Photomicrographs Used in Teaching Dental Histology S W CHASE
- 4 Figures Illustrating the Development of the Face Jaws and Teeth in
the Pig B M PATTEN
- 5 Skins of Hen feathered bantams Showing Effect of the Gonad Feather
Form and Color T S ELIOT
(Introduced by Dr F C Waite)
- 6 Activity Cage Used in Physiological Laboratory at Ohio State University
E P DURRANT
- 7 Charts in Genetics L B WALTON
- 8 Drawings Illustrating Origin of Pleurites in Insects I B WALTON
- 9 Specimens of Belgian English and American Coal Balls J HOBART HOSKINS
- 10 A Hamilton Fauna from Northwestern Ohio GRACE A STEWART
- 11 Siamese Twins of Arisaema of Opposite Sex JOHN H SCHAFFNER
- 12 Sex reversal in Japanese Hop JOHN H SCHAFFNER
- 13 Chimera like Sex expression in the Cat tail JOHN H SCHAFFNER
- 14 Leaf Series in the Rejuvenation Zone in Hemp JOHN H SCHAFFNER
- 15 Map Showing the Hydrogen ion Concentration of Lakes and Streams
of Ohio E L WICKIUFF
- 16 Graphs of Seiches and Tides on Lake Erie FREDRICK H KRECKER
- 17 Goniobasis Livescens from Varied Habitats R A HELFNER
- 18 Photographs Showing the Retention of Snow upon a Wind-swept Area
by a Heavy Rate of Seeding Wheat CLYDE L DIKE
- 19 Variations in a Species of Polyporus F O GROVER
- 20 Tomato Streak Artificial Inoculations W G STOVER
- 21 Two Fungi Parasitic on Other Fungous Species W G STOVER
- 22 Photo micrographs and Line Drawings of North American Species of
Deltoccephalus Species D M DI LONG
- 23 Illustrations of Foerster's Types of Odonata CLARENCE H KENNEDY
- 24 (Room 52 B & Z Bldg) Apparatus for Measuring Locomotion of
Earth Worms Under Controlled Conditions WM M BARROWS AND K C PRATT
- 25 A Culture of Englema on Clay F L FULMER

THE LATERALIS GROUP OF THE BOMBYLID GENUS VILLA

REGINALD H. PAINTER,
Department of Zoology and Entomology

The following notes are given in an attempt to make available a key and descriptions to a part of the "clear winged" species of the genus *Villa*. Together with the *Alternata* group and perhaps a few others, these species may be considered to constitute the entire genus as defined by Bezzi and the remaining American species of the old genus *Anthrax* would be distributed among several other genera. If his lead in this matter is followed at least two new genera will have to be made to receive some of these species, but the whole matter should receive attention only when the greater majority of the species of the old genus *Anthrax* and a considerable number of new specimens are available for study. The clear-winged species were named the subgenus *Hyalanthrax* by Osten Sacken (7), and may be distinguished as having

- 1 Front tibia with or without spines
- 2 Face very little projecting, convex
- 3 Third antennal joint short-conical, merging gradually into the style
- 4 Wings hyaline or with only C, Sc, 1st M, and R and the veins inclosing them darker

Most of the species may be divided as follows

- 1 Front tibia without spines, or if minute bristles are present the abdomen is two or more times as long as wide (slender) *lateralis* sub-group
- 2 Front tibia with spines or if these are lacking the abdomen is less than two times as long as wide (robust) *alternata* sub-group

In *V. lateralis* var *nigra* Cress, there are a few minute bristles on the front tibia and in *V. molitor* Lw the number of spines present is variable, possibly they may be absent in a few specimens. Outside of these two cases and one mentioned by Cresson (5, p 444) the presence or absence of these spines appears to be a usable character and the only structural one in the group.

All types unless otherwise stated are in my own collection

LATERALIS SUB-GROUP

In addition to the ones given in the key the following probably also belong here *gemella* Coq, *hircina* Coq, *nebulo* Coq, *squamigera* Coq, and *telluris* Coq. *Turbata* Coq and several of Cole's species are quite similar to this group of species, but are distinguished by having the mesonotum yellowish tomentose. No attempt has been made for an exhaustive study, but the material which was available has been described.

KEY TO THE SPECIES

- | | | |
|---|---|-----------------------------|
| 1 | Cell R and the base of R1 brownish | 2 |
| | Wings hyaline except sometimes costa and subcosta | 4 |
| 2 | Tomentum of face blackish or brown | <i>shawii</i> (Johns.) |
| | Tomentum of face light yellow or white | 3 |
| 3 | Dorsum of abdomen without black tomentum | <i>compressus</i> n. sp. |
| | Dorsum of abdomen with black tomentum | <i>jaunus</i> (Fab.) |
| 4 | A median longitudinal stripe of yellow tomentum on mesonotum | <i>muscaria</i> (Coq.) |
| | This stripe not present | 6 |
| 5 | A tuft of black scales on the sides of segment three | 6 |
| | Black scales on the sides of segment three and four generally absent or reduced to a few scattered ones | <i>salebrosus</i> n. sp. |
| 6 | Scales on sides of segment three brown to white, many brown scales intermixed with the usual black tomentum of abdomen and thorax, venter nearly all pale tomentose | <i>macorea</i> (Loew) |
| | Scales on sides of segment three black, tomentum not mixed, venter with bands of dark tomentum | 7 |
| 7 | Deep, reddish brown tomentose bands on segments 5 and 6 | <i>concessor</i> (Coq.) |
| | Tomentose bands on 5 and 6 the same color as the light colored tomentum on the remainder of abdomen or black | 8 |
| 8 | Scales on widened base of costa mostly yellow | <i>flavocostalis</i> n. sp. |
| | Scales on widened base of costa all or mostly black | <i>lateralis</i> (Say) |

Villa lateralis (Say)

The 177 specimens of this species and its varieties that I have examined come mainly from Texas and New Jersey, but also there are specimens from Ohio, Tennessee, California, Georgia, Ontario, Arizona, Kansas, Massachusetts, Colorado, and Iowa, Guatemala, British Columbia, Washington, and New York. For the typical specimens I have accepted Cresson's diagnosis of this species and followed his description (5, p. 440).

In addition to the genitalia the sexes may be distinguished as follows: (1) In the female a patch of long curly white or yellowish scales is present on the sternopleurae and overlaid by long thin hairs. In the male these latter are present but the scales are lacking. (2) The width of the front in the female is nearly twice that of the male. (3) In the female on either side of segment 7 of the abdomen there are small patches of silvery scales (in one or two very dark yellow or orange colored specimens these are yellowish). In the center the scales are black, often with some yellow scales at the base. In the male the number of silvery

scales varies from a condition in all respects like the female (*sabina* O S ?) to one in which all the scales on segment 7 are silvery. This character does not seem to be linked with the geographic distribution, for I have extremes of the series from both N. J. and Texas.

The ground color is generally black, often with the outer sides of segments 2 and 3 of the abdomen reddish. A specimen from Tennessee has most of the abdomen dark brown, otherwise it is a typical *lateralis*. The color of the lighter pile and tomentum varies from almost an orange to nearly white. There is considerable variation in the color of the scales on the venter of the abdomen and also in the amount of yellow scales on segments 3, 5, and 6, but these variations cannot be well enough characterized to give them a varietal name. The color of the knob of the halteres varies from white to dark brown without correlation with other characters. The costal and sub-costal cells vary from hyaline to dark brown. The scales on the mesonotum are brassy sometimes.

In view of the observations given above, *sabina* O S may be distinguished from *lateralis* only in having segment 7 with "a tuft of snow white hair on each side" (if it is hair). Osten Sacken had only a single specimen of *lateralis* from Eastern U. S. for comparison when he drew up the description of *sabina*. It seems that they are synonyms.

The Texas specimens were taken on *Tetraneuris linerae*, *Dicrophyllum marginatum* and *sumac* principally, and I have them from central and southern parts of the state. Possibly it is the commonest Bombyliid there and is found from March until November.

Varieties of V. lateralis (Say)

Coquillett, Johnson and Cresson from time to time have distinguished several varieties of this species and given them names. As indicated below some of these intergrade into the typical species, while others, according to our present collections, do not. Although it is often possible to distinguish only the more extremes of these intergrading forms, yet the naming of the varieties simplifies the placing of specimens in this variable species. I have not seen the variety called *gracilis* by Johnson (Canad. Ent., 15, p. 14), but the form is not the same as the one so-called by Coquillett, whose determination I have followed. I would therefore give this variety the new name *johnsoni*, retaining *gracilis* for the species described by Coquillett, which species belongs in the *alternata* group. Some varieties occur throughout the range of the species, others are more local, according to my material.

KEY TO *Lateralis* AND VARIETIES

- 1 Bands of light colored tomentum on abdomen wide a yellow tomentose triangle in front of scutellum 4
Bands of light colored tomentum on abdomen narrow or lacking, dorsum of thorax black tomentose 2
- 2 Pile of pleurae black *nigra* Cress 3
Pile of pleurae white or yellow
- 3 Tomentum of face yellow *aler* n var
Tomentum of face black and shining *johnsoni* n nom
- 4 All legs or at least femora reddish yellow in ground color *fulvipes* Coq 5
Legs black
- 5 Light colored tomentum of dorsum all of about the same shade, whitish yellow to golden, legs black *lateralis* Say 6
Light colored tomentum not all of about the same shade
- 6 Light colored tomentum white except on abdominal segment 7 and on pre scutellar triangle *arensicola* John
Light colored tomentum white or lighter only on 2nd segment of abdomen a very broad band of silvery scales in the male on abdominal segment 7 *faustina* O S

Var *faustina* (O S)

This variety was named as a distinct species by Osten Sacken, who, however had, at that time, only a single typical specimen of *lateralis* for comparison

The males may be distinguished by the very broad band of silvery scales on segment 7, which point inwardly from each lateral border and meet in an indistinct line down the center of the segment, second segment with a crossband of white scales thus lighter in color than the bands on the other segments. The border of golden tomentum on the posterior margin of the scutellum is replaced by black scales entirely in most specimens or reduced in others, color of entire lighter body pile and tomentum whitish yellow. The females are practically indistinguishable from the typical *lateralis*. The femora in both sexes are sometimes lighter in color, in this respect resembling var *fulvipes*, and from which they probably cannot be separated. Originally described from Mexico. There are 8 males from San Gabriel Mts, Cal, June and July, 2 males from Clear Creek and Chimney Gulch, Col, in the Ohio State University collection. Two females taken with the California males are probably the other sex of this form, they differ from *lateralis* only in having the crossband on 2nd segment slightly lighter. All specimens in the Ohio State University collection. I have also seen a female in the collection of R C Shannon from Ritzville, Wyoming, taken in August

Var *fulvipes* (Coq)

Differs from the typical *lateralis* only in having the femora and often all the legs wholly reddish yellow in ground color instead of black. The lighter colored pile tends to be rather whitish. One male and one female, San Angelo, Texas, Sept, 1 female, Brownwood, Tex, Sept, and in collection of R C Shannon, 1 female, Coules City, Wyo. In the O S U collection 1 female, Ira, Ohio, 1 female, Gualan, Guatemala, and 1 female, Clementon, N J

Another female, Austin, (April), in my collection, has all yellow legs but is suggestive of *faustina* on account of the white tomentum on segments 2 and 4

I have a male and 2 females from Austin (April) and Brownwood (June) in which only the basus of the femora are lighter in color. These must be considered to be intermediate between this variety and the typical *lateralis*

Var *nigra* Cresson

"Tomentum of abdominal dorsum, venter and patch on pleura entirely black or with narrow basal band on segment 4. Lateral scales of segments 3-6 entirely black or a few white on 4. The usual silvery scales on 7 present" (Cresson, Ent. News, 27, p. 442)

The tomentum of the face is grayish to shining. The variety may be distinguished from Var *johnsoni* [n. nom. for *gracilis* Johns (nec Macq.) (6)] by the color of the hair on the pleura. Six specimens, Ontario, Onaga, Kan., Framingham, Mass., Cincinnati, O., all males and all except the Framingham specimens in the O. S. U. collection, also 2 males in R. C. Shannon collection from Ann Arbor, Mich., and Tarrytown, N. Y. The specimens may be arranged in a series with regard to the amount of light colored pile on the venter, ranging from only a few white scales on the first two segments to one with a good many on each. The specimen from the last named locality, which has the most light colored tomentum on the venter also has a few whitish scales on the dorsum of segments 2, 3, and the sides of 4, the rest of the dorsum with black scales, thus showing a tendency toward the typical form.

In my collection there are four males from Riverton, N. J., and there is a male from Ames, Iowa, in the collection of Mr. Hull which have the tomentum of the face black with a grayish reflection in some lights. The hair is black on the pleura. These might be considered a separate variety but I doubt the necessity of separating them from *nigra*. All the specimens of *nigra* which I have seen have 3 or 4 very minute bristles on the front tibia, which are about half the size of those generally found on the *alternata* group.

Var *alter n* var

All tomentum of the dorsum of the thorax metallic, black and shining, edge of the scutellum with a few yellow scales, tomentum of face yellowish, pleurae yellow haired, whitish in the female. Otherwise as in *lateralis*. Length 10 mm.

Type Male, Riverton, N. J., July 28, 1920

Allotype female, Austin, Texas, Sept. 11, 1922

Paratypes 1 male, Riverton, N. J., in my collection and 2 males, Akron, and Ira, Ohio, in the O. S. U. collection

This variety has the yellow tomentose triangle of the front of the scutellum of the typical *lateralis* replaced by black scales. It is closely related to *nigra* and *johnsoni* and has the tomentose bands on the abdomen rather narrow. The venter has most of the segments with white scales.

Var arenicola Johnson

I have seen 15 specimens of both sexes from Coules City and Stratford, Wyom, in the collection of R C Shannon. The variety is well described by Johnson thus: 6 to 7 mm in length, with white tomentum and pile. The only yellow tomentum is a small triangular patch in front of the scutellum and sometimes scattered scales on the terminal segment of the abdomen. The second, third and fourth segments have prominent basal bands of white tomentum. This form seems to be more numerous in the spring (6)

Villa flavocostalis n sp

Tomentum of the widened base of the costa orange yellow, black scales along the anterior margin of the costa. All light colored tomentose bands of the abdomen very wide, 4, 5 and 6 with only a few rows of black scales. 2 and 3 with more black scales. Remainder of the structure and distribution of the pile and tomentum as in *lateralis*. Length 13 mm.

Type female San Angelo, Texas, Sept 13 1921

Paratypes 2 females Brownwood, Texas, June 17, 1921, and Sept 22, 1925

This may be only another variety of *lateralis* but it will require more specimens especially males to tell for certain. The appearance is quite distinctive.

Villa concessor (Coq.)

A female from Miner's Peak Utah, in D G Hall's collection and a male in my own collection from Brownwood, Texas, Sept 22, 1925, and a male in the Ohio Collection from Los Angeles Co., Cal. Cresson considered this a variety of *lateralis* but the deep reddish brown tomentose bands on the 5th and 6th segments are quite striking. I have never seen this condition approached among the typical *lateralis* specimens which never get darker than a golden yellow and this equally on all segments. The sparse pile on the thoracic dorsum is twice as long as it is in *lateralis* in relation to the size of the specimens, and the appressed blackish tomentum of the thorax has a much more metallic luster.

Villa mucorea Loew

In general appearance much like *lateralis* but somewhat stouter. The chief differences are: Black tomentum much interspersed with brown, seeming to alternate in indefinite longitudinal stripes on the mesonotum. The usual yellowish tomentose triangle in front of the scutellum mixed black and brown tomentose with whitish tomentum on all margins of the scutellum. All pile white, short and erect on dorsum of thorax. Brown to white scales on the sides of segment 3 (where they are black in *lateralis*). Abdominal pattern much like *lateralis* but the tomentum is brown in *mucorea* where it is black in the former.

Loew had a single female from Nebraska, and I have seen in R C Shannon's collection 2 males from Stratford, Wyom, Sept 4th, and Ritzville, Wyom, Sept 9th. Taking into consideration the differences in sex they agree very well with Loew's description.

Villa salebrosus n sp

Female Ground color black, pile and tomentum of face, and tomentum of front silvery, pile of front black, pile and tomentum of first joint of antennae silvery below, black above Thorax marked as in typical *lateralis* Sides of the abdomen at the base with a long yellow bushy pile which emerges into long scales on the sides of the 3d segment The scales are black on the sides of segments 5 and 6 and yellow on 7 There are two or three black scales on the sides of segment 3 The black tomentose crossbands on the dorsum of segments 1 to 4 do not reach the sides but are half lens shaped A fringe of black scales on the apex of segments 5, 6 and 7 Venter white tomentose, a narrow band of black tomentum on the bases of segments 3, 5, 6, and 7, and a spot in the center of the base of segment 4 Legs black, black tomentose Femora with white tomentum at the base Length 12 mm

Type Female San Angelo, Texas, Sept 13, 1921

Paratypes Two females, Brownwood, Texas, Sept 16, 1920

The erect yellow pile on the sides of the abdomen gives this species an appearance different from typical *lateralis* or *flavocostalis*

Villa muscaria Coq

There are 2 females and 1 male specimens in the collection of O S U from Montclair and Berkeley, Cal , in August and September The principal characters of the species are the median longitudinal yellow tomentose stripe across the center of the thorax, the black tomentum at the apex of segments 5 and 6, and the legs chiefly yellow This species and species *salebrosus* differ from the others in having the black scales of abdominal segment 3 largely replaced by yellow ones, the thoracic stripe is not prominent in the male

Villa fannus Fab

There are three specimens from Onaga, Kan , and one from Spring Creek, Ga , which are thus labeled in the O S U collection and evidently are similar to the specimens which Coquillett had There is a female of this species in the collection of H J Reinhard, taken at Moore, Tex , June 7 So far as I can tell they differ from *lateralis* only in having expanded costa with a patch of yellow scales among the black, and in having cells C, Sc, 1st M, R, and the base of R5 and R1 quite brownish

Villa compressus n sp

Male Ground color, dull black Genitalia and 1st joint of antennae yellowish red Face and front yellowish tomentose and black pilose, a patch of large white scales between the antennae and on the lower part of the front First two joints of the antennae black haired Occiput white tomentose and yellowish pilose Thorax yellow pilose, on sides and in front short black, scattered pilose on dorsum A patch of white pile below the root of the wing and extending to the front of the thorax The tomentum of the mesonotum consists of narrow yellow scales with a V-shaped stripe of white ones about one-quarter of the way from the

front of the thorax. Longer white tomentum above the roots of the wings and at the base of the scutellum form with this stripe an irregular circle on the dorsum of the thorax. Remainder of the scutellum yellow tomentose. Spines of scutellum and thorax yellow. Abdominal tomentum of narrow scales mostly yellow, wide white stripes of tomentum on the bases of segments 3, 5, 6 and 7. Pile white on the sides as far down as the middle of the 3d segment, beyond that they merge into long narrow yellow scales intermixed with stiff black hairs. Similar hairs on the apex of each segment and on the coxæ. A tuft of white pile behind the wings and halteres. Length 7 mm. Wings hyaline except cells C, Sc, R, and a trace of a cloud on the bases of Cu 1 and R 5.

Type Male, Brownwood, Texas, Sept 16, 1920, in my own collection.

This specimen runs to *inculta* in Coquillett's key (Trans. Am. Ent. Soc. XIX, July, 1892), but differs in the coloration of the antennæ and vesture of the face and abdomen.

This species differs from the remaining species dealt with in this paper in a way which is difficult to characterize. The smaller size, shorter but broader abdomen and the tomentum which consists of very narrow scales, seem to be the more important differences. The following species, which I have seen in the National Museum, and perhaps some others are quite similar, *inculta*, Coq., *crocina*, Coq., *tantilla*, Coq., *variata*, Coq., *cinefacta*, Coq., *terrena*, Coq., *gemella*, Coq., *hiercina*, Coq., *torbala*, Coq., *anna*, Coq., *comparata*, Tucker, and *alta*, Tucker. Possibly they constitute at least a separate group but lack of material has prevented my further study of them.

Villa shawii Johnson

There are 3 females and 1 male from Clementon and Iona, N. J., in the O. S. U. collection. This species is easily distinguished by the dark orange pile, dark tomentum of the face, and the brown anterior border of the wing. Cell R and R1 are also dusky in these specimens.

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THE NATURAL VEGETATION OF OHIO

III PLANT SUCCESSION

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PRELIMINARY STATEMENT

In the preceding papers of this series (1) it has been shown that within the glaciated area the physiographic results of glaciation offer the best general key to the pattern of natural vegetation. The results of glaciation, in turn, have been largely influenced by preglacial conditions.

In analyzing the composition of the natural vegetation of Ohio certain groups of associations were distinguished, to wit, Prairie, Ash, Oak, and Beech. Each group includes several related classical associations as described by Cowles (2) and others.

Geographical influence is very marked in the detailed composition of these association groups. Plants whose centers of distribution—in the sense that Waller has employed the term (3)—lie outside of Ohio, occur under proper ecological conditions in those parts of the state most accessible to them. The southeasterly (xerophytic), southern and southwestern (generally mesophytic) elements in these admixtures are most widespread and the boreal least so. Northeastern and western elements are of intermediate importance.

The task of the present, concluding, paper of the series is to develop salient facts with regard to the natural plant succession, particularly in the glaciated Erie Basin. Since the aim is essentially historical, no space will be given to discussion of the excellent detailed modern work of Jennings, Dachnowski, Schaffner, and others, further than to state that their results seem to be entirely consistent with those obtained from a study of early sources.

It will be recalled (1) that Riddell's Western Flora contains considerable habitat data, especially with reference to prairie and related associations. Fig 1 represents a tabulation of all species listed by him according to habitat. Apart from the very large group which must be classed as miscellaneous in

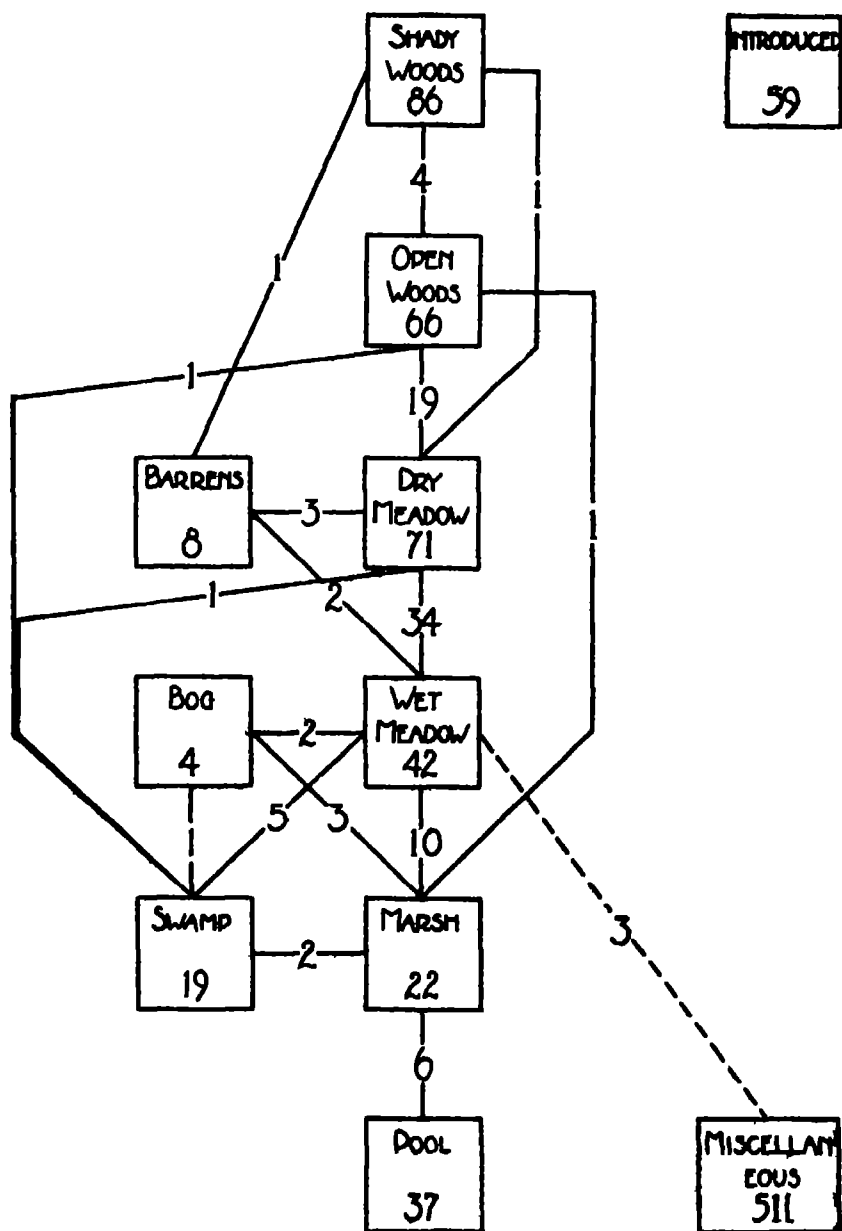


Figure 1

Succession diagram obtained by statistical analysis of habitat notes in Riddell's Western Flora, 1838. The number of species peculiar to each distinctive habitat was obtained, also the number of species occurring in more than one habitat. The resulting sequence is perfectly definite.

habitat, it will be seen that certain very distinct habitat groups appear. Moreover, if these groups be arranged so that those having large numbers of species in common are in juxtaposition, a very definite sequence develops for the whole series. This sequence, beginning with open water (Pool), runs into Marsh, Wet Meadow, Dry Meadow, Open Woods, and culminates with Shady Woods. Swamp, Bog, and Barren form offshoots of the main series. It is a curious fact that only the hydrarch succession can be developed from these habitat notes, data on the "miscellaneous" species being so vague ecologically that it cannot be analyzed. However, we know that Riddell's peculiar interest lay in the prairie, nor did he seemingly appreciate the problems suggested by great areas of swamp forest ("Ash") in northwestern Ohio, although he visited this district in 1836 (4). Neither is it surprising that, living as he did in southwestern glaciated Ohio, the xerarch series of the unglaciated region failed to resolve themselves clearly in his mind. Botanists more recent than Riddell have had their troubles with these series.

Something of the inherent difficulty of analyzing the xerarch series becomes evident by inspection of our next line of historical evidence, to wit, a tabulation of notes made by the first geologists, (5).

These notes have been arranged below in order of the age of the rock strata examined as nearly as the same can be identified. Only the unglaciated region is here considered.

2nd Report 'Blue Limestone' (Ordovician)

- p 207 Trees even on wet upland flats which however dry early
- p 216 Wet bottoms drying early very fertile—gigantic sugar maple, oak, black walnut, elm, sycamore, hickory honey locust ash, etc

"Great Marl Stratum" (Upper Silurian)

- p 243 Mound like outliers "bald hills"—coarse prairie herbs. Levels—white oak flats
- Talus slopes, sugar maple p 250, "coves of talus id

"Cliff Limestone" (Upper Silurian)

- p 212 Cliffs, etc., topped by cedars p 252 p 256 id
- p 253 Thin soil, nearly level—white oaks p 254, terrace—common oak p 266, oak forest
- p 252 Hillside showing huckleberry and chestnut which are scarce on limestone—(but this hill was capped with sandstone)
- p 269 Slope—fine oak forest with service tree and shrubby Hypericum
- p 242 Level loam-covered, fertile—hickory oak, black walnut, sugar maple, dogwood, sassafras and gigantic poplar—the characteristic tree

"Slate" (Upper Devonian)

- p 270 Disintegrating slate—almost barren a few pines
- p 251 Residual soil—cedar, pine, chestnut oak
- p 262 Hillside, abundant sweet gum slopes, sugar maple, etc
- p 254 Hillside showing huckleberry and chestnut "the signs of slate" (this hill was capped with loose sandstone rolling down)
- p 260 Broad slate bottoms—heavy growth beech sugar maple and tulip tree

'Sandstone (Lower Carboniferous)

- p 270 Cap of hill—grassy p 255 Cone top of sandstone fragments—vines, young chestnuts andropogon osmunda, near top grass and copse on top
- p 253 Hill-caps—chestnut oak
- p 262 Id covered with stoneless clay—andromeda huckleberry, scattered hickory and oak
- p 266 Hill—plants of sandstone formation as huckleberry and chestnut
- p 259 Sandy gravels along sluggish streams—*Nymphæa odorata* which seems not to thrive on limestone
- p 269 Ascent, mixed with slate—two species of huckleberry
- 1st Report p 103 (Alluvial mixture) Scioto bottoms, lower—sycamore, cottonwood, black walnut
- Scioto valley sides—general mixture of 'western' trees including locust and paw paw

'Conglomerate' (Lower Carboniferous)

- 2nd Report p 131 Topped by oaks or evergreens
- p 130 Dclivities—often covered by evergreens
- (Upper Carboniferous Pottsville and Alleghany Series)
- 1st Report p 102 (Sand) rock knobs pine on n and w slopes, oak elsewhere
- p 36 Calcareo-siliceous region—heavy forest of largest trees, esp chestnut and tulip tree
- (Id, Monongahela & Dunkard Series)
- p 50 Thin fissile slaty hard sandstone—only stunted scrub oaks and vines
- p 40 Light sandy loam on loose sand rock of lofty ridges—chestnut and chestnut oak
- p 49 Sandy loam on coarse sand rock above limestone and marls—yellow oak chestnut and tulip tree
- p 45 Sandy Pomeroy Series lime shale sand mixture—very fertile, heavy forest sugar maple and beech to tops of hills
- p 40 Calcareo-argillaceous chocolate colored soils on red shales—present limits yellow pine
- p 49 Non fossiliferous limestones and marls—uplands heavy forest chiefly oaks and hickories containing abundant remains of yellow pine, but only occasional living specimens of same
- p 50 Limestone residual soil—fertile alluvial type of forest to tops of hills

Two facts at least emerge from a study of the above somewhat confusing list of observations. In the first place there appear to have been selective effects exerted by some of the residual soils, which tended to disappear on weathering and in mixtures. In the second place, so far as our evidence goes, the progress of physiographic development was accompanied by a marked trend toward mesophytism upon all of the rocks.

Our next line of evidence is derived from contemporary description of actual successional phenomena upon glaciated country, principally within the Erie Basin. From among a great many observations the following are selected as most illuminating.

In Stark County, near Waynesburg, in Sandy Township, the first settlers saw young oaks coming up everywhere amongst

rank prairie grass (6, a) Read (7, a) in discussing the physiography of Huron County, describes a primitive forest mainly of large oaks growing upon an old swamp consisting of several feet of black mold He also describes the physiographic history of a filled swamp which he found largely occupied by yellow and swamp oaks Parts of Tiverton Township, Coshocton County, (6, b) were covered when first settled with a low underbrush of oak over which a wagon could be driven White oak, accompanied by elm, ash, white thorn, elder and plum, composed the scattering trees of a grassy intervale on the 6th meridian (8, a) between Ashtabula and Geauga counties The succession on the poorly drained flat between the Miami and Stillwater rivers in Miami County, is described by John Hussey (9) as beginning with sedges, "mosses," etc, followed by elms, soft-maple, buttonbush, etc, leading on to burr oak and ash The oak openings of Fulton County (6, c) were stabilized dunes, with lagoons occupied by marsh and prairie and the rounded hills showing no tree but oak, and this only in the flatter portions It is to be noted, however, that with settlement and the discontinuance of Indian fires, the growth of oak became very dense in parts of the oak cpenings, instead of sparse as theretofore, while aspen appeared in some of the drier prairies, (10, b)

The first surveyors of Mahoning County encountered, 3rd Merid, 10th M₁, (8, b) a soil "of a hard pale coloured marle or clay & * * smart to taste * * the Timber * * White Oak, Hickory & * * various kinds of Whortles" Oak-chestnut covered the hills of Portage (11) and Coshocton (6, b) counties, while on the clay uplands of Greene County (12, a) and the cold, poorly drained till of Madison County (12, b), there was little timber beside oak In the latter county this consisted of *Quercus palustris*, *Q. obtusiloba* and *Q. alba*, on somewhat better land—clay over gravel—bur oak was found, while the upland gravel "points" of Greene County bore black walnut, sugar, blue ash, and hickory in contrast to the oak of the surrounding clay The heavy clay moraine near Defiance (13) was covered by oak woods with hazel undergrowth Adjacent was a French and Indian cornfield of over 1,000 acres This field is called a prairie by Spencer, who was a captive among the Indians, but elsewhere is spoken of as a clearing In the first survey of Trumbull County, (8, b) 3rd Merid, 13th M₁, the following notes were recorded "water, but does not run * * thicket [of vines & briars & willows, small popples, thorns, crabtree,

cherry, oak * * spots of grass, Angelica & Golden Rod]
 soil excellent * * some Hazle bushes * * also now and
 then a stately White Oak which escaped the fire, the cause of
 the thicket * * to a ridge of White Oak "

Turning next to stages of succession beyond the oak, the first reconnaissance of Medina County (8, c) noted as remarkable the absence of beech in the eastern half of Tp No 4 N , R 13 W. The other timber here was linden, hickory, black oak, chestnut, and cucumber. The western half of this township, which even on modern maps is clearly more mature physiographically than the eastern, contained beech, sugar-maple, chestnut, and hickory. Fulton Township, Fulton County, (6, c) in its primitive state was covered with a heavy growth of timber consisting of white oak, some red oak, elm, ash, and a large amount of cottonwood, interspersed with tulip tree and some linden. Beyond the grassy intervale between Trumbull and Geauga counties, already referred to in the preceding paragraph, lay gently rising land with many small white pines growing amongst oak and ironwood. In Portage County (11) when the white man came the juvenile topography of the hills was occupied by oak-chestnut and that of the depressions by ponds and bogs, while the relatively more mature topography of the level lands was covered by beech-sugar maple forest. The whole tract now covered by Cleveland (6, d) was a sandy loam, covered with a mixture of chestnuts, oaks, elms, maples, and beeches with large trunks. In Lorain County, Tp 2 N , R 18 W on soil of good quality T Kirtland (8, c) and his associates found in the eastern part "large Oak and small Timber Beech Sugar tree and here it is apparent that the kinds of Timber have been shifting for considerable time "

Having thus some contemporary evidence that oak forest, xerarch or hydrarch was eventually being succeeded by beech-sugar maple mesophytic, it is interesting to examine some records which throw light on the purely hydrarch forest succession. In Tp 4 N , R 18 W , Lorain County, (8, c) the forest was beech-sugar maple, mixed with ash, elm, and linden, but on the so-called "scalded" patches of land the trees were sycamore, black ash, and white ash. In the same county and township but in R 16, (8, c) the forest was scalded beech-sugar maple, with black and white ash "remarkably straight and tall ". In Portage County, 7th Merid , Tp 4 N (8, d) was found a willow swamp, adjoined by ash land, cold, wet, and plain.

The timber here was black ash, birch, maple, beech, and some swamp oak. Howe (13) in giving an account of the Black Swamp as found in Henry County, describes the dense and uniform growth of forest-trees, "among which beech, ash, elm, and oak, cotton-wood and poplar most abound." He also states that the limestone ridges running through the swamp were covered with black walnut, butternut, red elm, and maple, while flood plain species occupied the gravel ridge at Van Wert. Riddell (4) in his brief mention of the Black Swamp as he saw it in Wood, Lucas, and Ottawa counties, notes the fine black soil, underlain by limestone, and describes the forest vegetation as very similar to that on the level tracts of the Scioto and Miami rivers. Oaks, hickories, black walnut, and cottonwood seemed to him especially abundant.

In the 22nd M₁ of the 6th Merid., between Trumbull and Portage Counties (8, a) was a swamp of willow, alder, maple, ash, and gray birch, with low beech ridges. Read (7, b) in discussing the filled valleys of Knox County states that they had so much gravel that walnut and maple was the usual growth instead of [oak and prairie] as in the clay-filled valleys. The surface soil of Wayne County, (6, c) was pronounced friable, except in the beech and marshy districts. Where the 6th Merid. was run between what are now Ashtabula and Geauga Counties (38th M₁ N) Pease (8, a) observes "besides Alders and swampy shrubs there is Elm, Butternut, and Ash Staddles and they appear to be the first of the kind ever produced here. The Alders are the largest I ever saw and are by far the biggest Timber in the Swamp it is not a miry place the horses passed it loaded * * * [beyond] is grass and Solandine * * * the upland is gently rising good land * * * Timber, Maple, Beech, Oak, Cherry, Bass, Elm, and Ironwood." Read (7, c) in his geological report on Lake County, states that the dense forests of elm and black ash found in places in the northern part of Willoughby and Mentor Townships indicate areas long occupied by shore swamps.

There is little doubt that wooded swamps, even those containing alder and birch, were passing through a succession involving ash, or at times, oak, as prominent genera. The latter stages in turn were succeeded by a mesophytic forest in which beech and sugar maple were conspicuous. Such seems to have been the genesis of the wet beech flats in north-eastern Ohio and the general tendency of the more fertile Black

Swamp of the northwestern region What factors favored oak swamp forest as against ash is not clear There is some reason to regard water relations as the key, the oak swamp being, perhaps, more resistant to summer drought Species of oak

Y	Y	L	F	I	±	±
ROSA	PRUNUS	CRATAEGUS	POPULUS	QUERCUS	CARYA	
L	+	T	±	I	F	F
SALIX	FRAXINUS	ULMUS	CELTIS	PLATANUS	AESCULUS	LIRIODENDRON
T	+	L	F	I	±	±
FAGUS	ACER	CARPINUS	CORNUS	LIQUIDAMBAR	TILIA	JUGLANS
L	+	T	±	I	F	F
ALNUS	SASSAPARILLA	HAMAMELIS	ROBINIA	BETULA	MAGNOLIA	CASTANEA
Y	Y	L	F	I	±	±
JUNIPERUS	LARIX	THUJA	PINUS	ABIES	PICEA	TSUGA

Y P VIRGINIANA	I ^{sw} Q ALBA	I ^{sw} Q FALCATA	I ^{sw} Q MACROCARPA
I ^{sw} Q MARILANDICA	I ^{sw} Q PALUSTRE	I ^{sw} Q RUBRA	I ^{sw} SWAMP oaks
T ^{sw} F AMERICANA	T ^{sw} F NIGRA	T ^{sw} U AMERICANA	T ^{sw} U FULVA
T ^{sw} A SACCHARUM	T ^{sw} A RUBRUM	L ^{sw} OSTRYA SA	I ^{sw} L NIGRA
I ^{sw} J CINEREA	I ^{sw} G LEDITSIA SP		

Figure 2

Key to mapping symbols used Above generic symbols, below, species or special genera

were numerous and included a fair range of physiological types, but we must agree with Gleason (14, a) that the genus is relatively immobile Certainly the relation of swamps to adjacent forest, rodent ecology, germination requirements, and rooting habits must all have been elements in the problem

Mention should be made of an observation recorded by Lesquereux (15) who states that swamp rose and buttonbush require rotten logs for the germination of their seeds in swamps, the roots then penetrating the soil during the dry season and becoming established. This may give a valuable clue to the puzzling fact that some swamps remained herbaceous

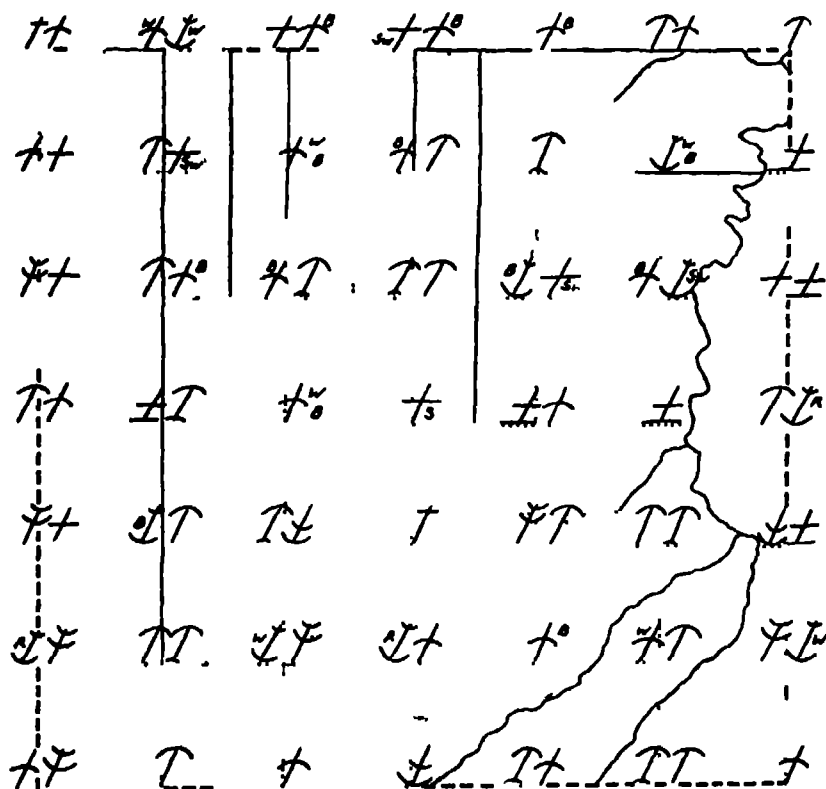


Figure 3

Present drainage and original forest of Tp 4 N, R 8 E, Henry Co. Forest an advanced stage of the ash-elm-maple-cottonwood association, topography youthful as the rectangular ditches indicate

indefinitely, while others seemingly much like them, became wooded very rapidly

The early records contain substantial evidence that land subsidence, beavers, and Indian culture all have had marked effect on successional history. One cannot spend many years on the problems of Ohio vegetation without becoming con-

vinced of the profound importance of a better knowledge than we now have concerning ethnological factors and reactions

Coming now to the detailed forest map of Ohio (1) based upon the bearing trees at one mile intervals what information does it supply with respect to natural succession? The general morainal relation of Oak Beech and Ash types as pointed out

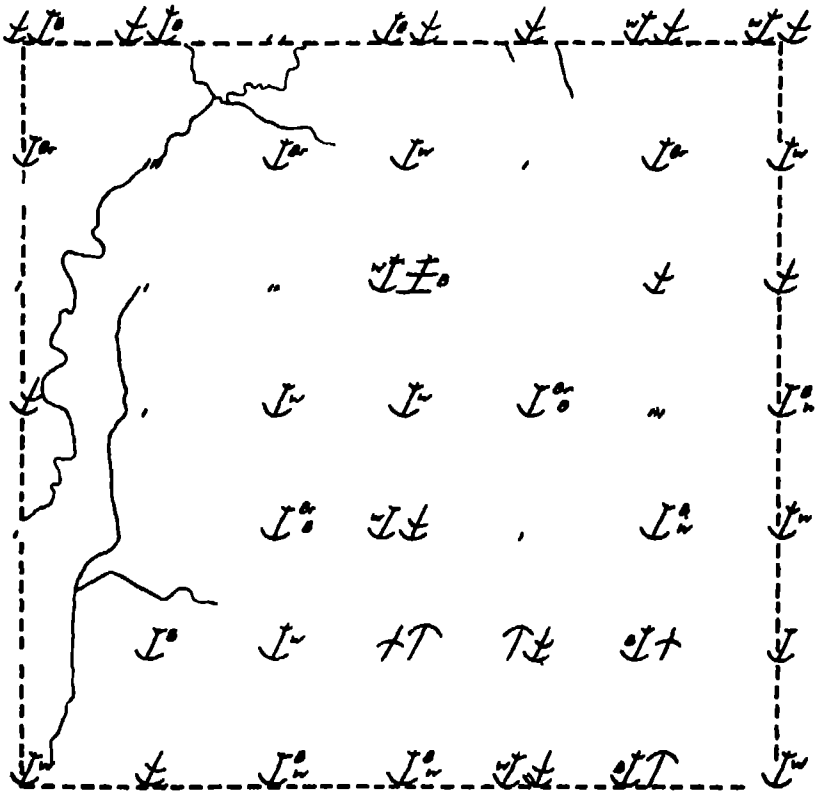


Figure 4

Present drainage and original forest of Tp 5 S R 15 E Marion Co. Vegetation white oak black oak bur oak hickory prairie topography youthful

in Part I certainly suggests that the mesophytic Beech occupies the most mature region physiographically of the three

In Fig 2 are reproduced as a key to the figures following the mapping symbols used to designate various species of trees transcribed from original survey records Fig 3 represents Tp 4 N R 8 E in Henry County surveyed in 1821, (16)

showing the species of bearing trees at section corners at that time. The drainage is mapped as shown on the McClure Sheet done in 1906-7 (17). Most of this drainage it will be noted consists of rectangular ditches made since the region was settled. The forest cover is typical for the Black Swamp region consisting largely of white and black ash elm maple cottonwood

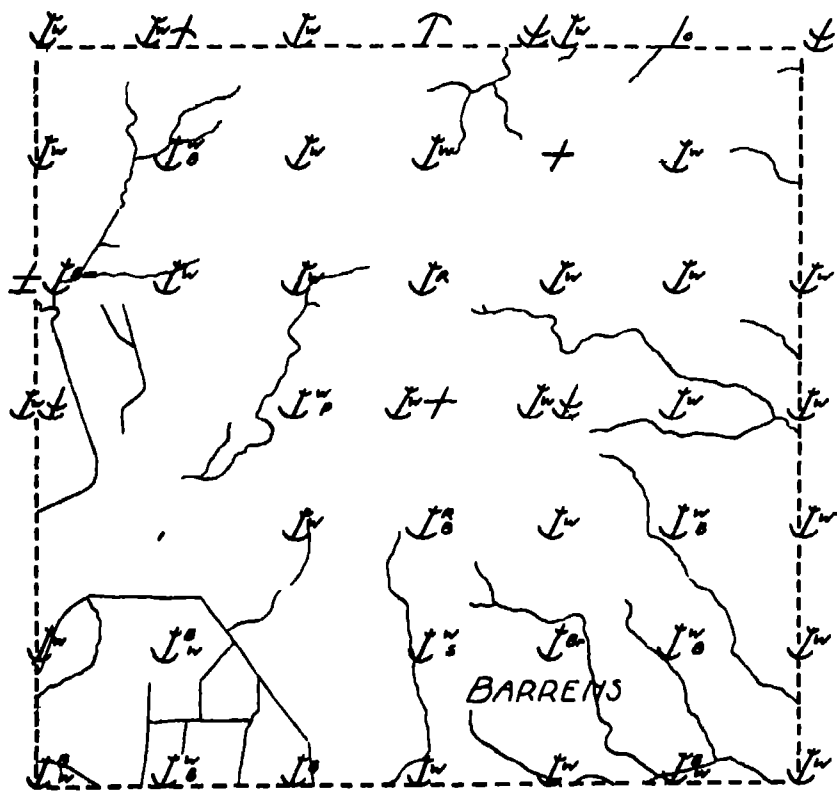


Figure 5

Present drainage and original forest of Tp 9 N R 14 W Wayne Co. Forest mostly oak black and white artificial ditches and centrifugal stream heads indicate youthful topography

with some oak and hickory and even the more mesophytic linden tulip tree and beech in places. The extensive ditching indicates clearly enough the youthful physiographic character of this forest association.

The Oak group of associations is represented in two of its phases in Figs 4 and 5. Fig 4 records the trees present in

Tp 5 S, R 15 E of Marion County (16) when originally surveyed, (about 1810) Black oak-white oak, bur oak, hickory, and prairie are conspicuous. The drainage was mapped about 95 years later, in 1905 on the Marion Sheet (17). It is known to be much more extensive than formerly (I, II), but is obviously still far from mature. The other area, Tp 19 N

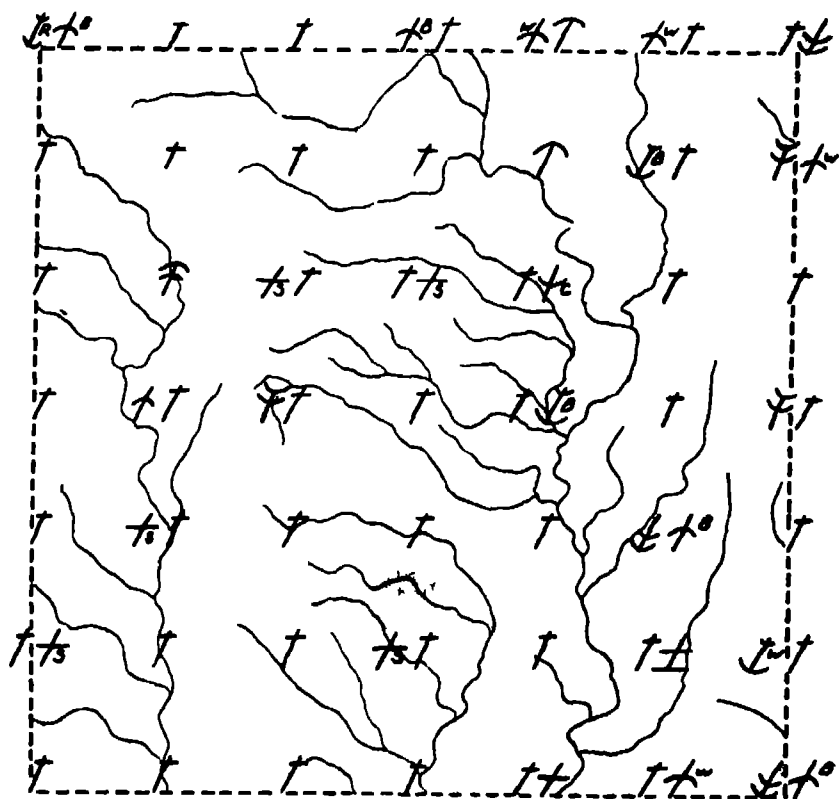


Figure 6

Present drainage and original forest of Tp 2 S, R 11 E, Hancock Co. Beech-sugar maple association, drainage pattern fairly uniform and mature

R 14 W of Wayne County (8, b) was predominantly white oak and black oak (16). Seemingly well drained, it is actually quite youthful physiographically, as the diverging stream heads and the ditches at the western and southwestern edge bear witness (West Salem Sheet, 17). The trees were recorded here in 1807, the drainage between 1905 and 1912.

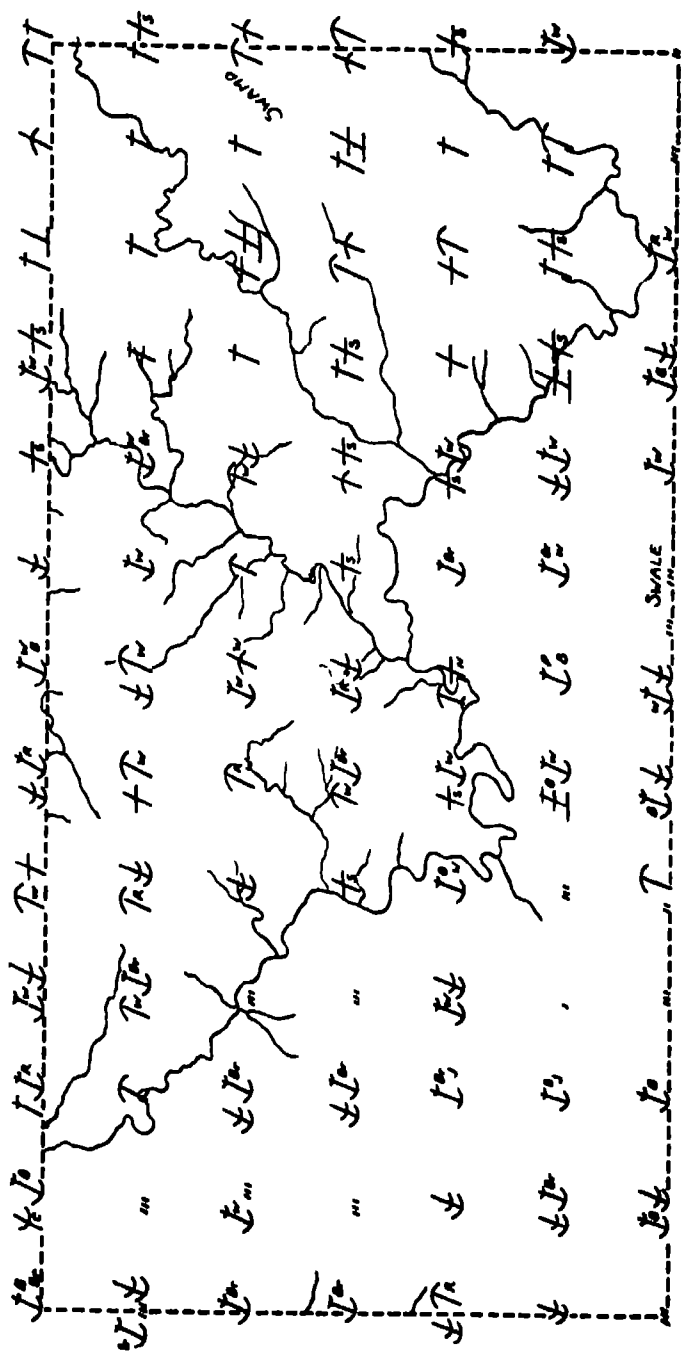


Figure 8

Original drainage and forest of Tps S S , Rs 14 and 15 E , Wyandot and Crawford Counties Organized drainage almost null in prairie-oak-hickory mixture at bottom and left, better in transition zone of upper center, best in beech-maple at right

and 9 of Tp 3 S, Rs 14 and 15 E in Wyandot and Crawford counties are of interest. In Fig 8 is represented not only the forest but also the drainage as mapped in 1819, about 10 years after the original survey (16) (18). The absence of any organized drainage whatsoever in the prairie-oak-hickory area to the south of the Sandusky river is striking, while in the eastern area north of the river, occupied by beech and sugar maple, the drainage is clearly well developed. The triangular patch* in the north center of the map shows drainage somewhat developed and here instead of prairie and oak is elm, maple, and

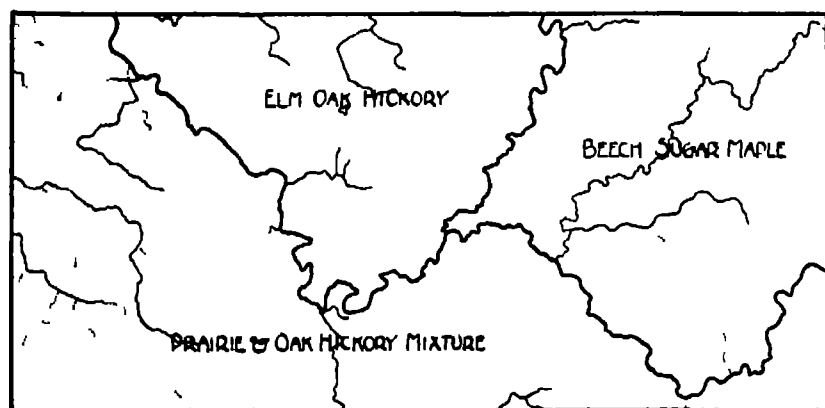


Figure 9

Same area as Fig 8, drainage as at present. Note rapid extension of drainage in prairie oak hickory region since settlement.

oak. In Fig 9 is recorded the present drainage of the same area. The most considerable change has been the extension of drainage in the originally undrained prairie-oak-hickory area, tending somewhat to lessen the physiographic contrast between it and the more advanced successional stages. This type of change has occurred rather generally in hydrarch areas, making it all the more remarkable that in every case examined there is still visible a definite correlation between the character of the native vegetation and the degree of physiographic maturity as judged by present conditions.

*Riddell, entering this patch from the west in 1836, describes it as follows (4): "After crossing the Sandusky, we traversed two miles of plain, where the prairie and woodland vegetation contend for mastery. The trees then began to occur more closely together, and we soon had a dense, unbroken forest."

CLIMATIC CONTROL

In constructing the trend of succession in a given region the broad climatic tendencies are of first importance. What evidence is afforded by the natural vegetation on this point?

1 J G Kirtland, a most excellent naturalist, who knew the native fauna and flora of Ohio well (19) pronounced the flora of the southern shore of Lake Erie mainly southern, but with some hyperborean elements. Certainly boreal associations, in the form of bogs, while frequent, were not extensive nor aggressive. For example, none were found within the great hydrarch area last vacated by Lake Erie and enclosed within the ancient shore lines of Lake Whittlesey. This means apparently that such boreal associations have not been initiated within more recent postglacial times. What is more, in a great number of former bog habitats, which give every evidence of having been occupied by boreal subclimax the present vegetation consists of non-boreal successors, e g, beech and sugar maple.

2 Plants whose centers are westerly, such as *Andropogon furcatus*, *Tilia americana*, *Ostrya virginiana*, *Quercus macrocarpa*, etc., although numerous in northwestern Ohio, are all clearly members of subclimax associations. In this region the bulk of space has for a long time been occupied by subclimax plants and the most active, hence most significant phase of succession climatically is that which leads on to climax associations. As will be seen later, the climax here includes beech and sugar maple, with other forms decidedly more southern than western.

3 In the nonglaciaded region of deep relief the most active changes are due to erosion. Aggressive associations would be expected then in the uplands, xerophytic, and predominantly southeastern in their forest cover. Mesophytes of northeasterly origin such as *Tsuga* were largely confined to isolated ravines, long stabilized, and were certainly not as abundant in the natural climax as *Fagus*, *Acer saccharum*, *Magnolia acuminata*, *Liriodendron tulipifera*, etc.

4 Much of central and southwestern glaciaded Ohio has been long since covered by subclimax vegetation. Here again the most active phase of succession is from subclimax on

There is no question that apart from *Acer* and *Fagus* the predominant mesophytes in this portion of Ohio, e g, *Aesculus*, *Juglans*, *Liriodendron*, etc, have southern and southwestern centers of optimum growth

5 The behavior above described for western as well as boreal forms suggests a retreat from Ohio—more recent for the western than the boreal This accords with the general theory of postglacial northward movement of boreal vegetation and with the hypothesis of an ensuing period of continental climate (14, b) If one postulates an Arctic-Labradorean-Manitoban sequence of climate for Ohio this does not seem unreasonable But a xerothermic hypothesis which assumes Arctic-Labradorean-Coloradoan climates in sequence is harder to follow

6 Reviewing these five propositions we arrive at a definite suggestion with reference to climatic trend as expressed in natural vegetation between 1798 and 1835 The aggressive phases of natural vegetation in Ohio were southerly in their general character and indicated a continuing northerly trend of southern climate

SUMMARY

1 In this third and concluding paper of the series on Natural Vegetation of Ohio the historical method has been extended to an attempt to reconstruct the natural plant successions

2 Since the data available for this purpose consist largely of the observations of men who perceived the process of succession incompletely or not at all, only the broadest general outlines can be derived

3 By analyzing and plotting the habitat data of Riddell's Synopsis of the Western Flora the hydrarch sequence of much of glaciated Ohio was found to consist of the following series Water, Marsh, Wet Meadow, Dry Meadow, Open Woods, and Shady Woods Bog and Swamp seem to represent restricted offshoots from the main course of succession, at least in Riddell's experience His data fail to shed light on either the xerarch series or the series involving swamp forest

4 Tabulation of observations published by the Geological Survey in 1838 confirms the findings of Part I regarding the selective influence of rock beneath residual soils in unglaciated

Ohio This tabulation also shows progressive mesophytism accompanying physiographic development in unglaciated Ohio

5 Field observations of the first surveyors and of early naturalists have been studied They indicate clearly the existence of a trend toward mesophytism in all parts of the state that have been glaciated In xerarch successions the oaks were conspicuous, accompanied by chestnut on silicious soils In hydrarch successions, following the wet meadow, ash was conspicuous along with elm and soft maple Oak frequently played a part in the hydrarch series, but was often lacking The oak stage in any series yielded to hickory, red oak, linden, sugar maple, and finally beech, to which was added white ash, tulip, and other mesophytes (In mellow soils, however, such as rich sandy alluvium, or gravelly upland clay, the final mesophytic stage containing beech seems to have been preceded by one in which hickory, sugar maple, black walnut, and tulip tree were prominent) On stiff, wet clay flats, ash swamps were succeeded directly by beech, often in fairly pure stands Here the other mesophytes made but slow progress, but were not altogether absent

6 Maps of the original section corner trees showing the present drainage indicate clearly, in spite of the lapse of time, that beech-sugar maple mesophytic forest occupied the most mature ground physiographically, while the subclimax and pioneer associations, such as oak-prairie, black oak-white oak, ash-elm-maple, etc., were found on relatively youthful topography

7 The climatic trend, as judged by the character of associations actively developing in the native forest, seems to have been in favor of southerly forms

8 The climax forest seems to have been a modification of beech-sugar maple in the direction of mixed mesophytic forest

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PHYSIOLOGY OF STOMATA OF RUMEX PATIENTIA*

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INTRODUCTION

The periodicity of transpiration cannot be satisfactorily explained until more is known about the exact behavior of stomata. The object of this paper is to record certain investigations of the conditions and changes occurring within the leaves and in the environment which are correlated with the high day and low night rates of transpiration. These investigations have been confined to a single species of plant, patience dock—(*Rumex patientia* L.) and the conclusions drawn apply to this plant, and perhaps to others.

Continuous records of environmental factors and of transpiration have been obtained, and synchronous observations of stomatal pores, starch content, sugar content, osmotic values, and H-ion concentrations of the guard cells have been made. The results are reported in the following pages †

Patience dock was selected for this work because it has very large guard cells. The epidermis which is only slightly cutinized can be very easily removed from the large smooth leaves which are entirely free from epidermal hairs or appendages. The plants grow readily in the greenhouse or in the garden.

Stomata are present on both surfaces of the leaves. Numerous counts showed more per unit area near the margin than near the midrib of the blade and more near the tip than the base of the blade. On mature leaves they average 32 per square

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millimeter on the upper surface and 49 per square millimeter on the lower surface of the leaf. The guard cells which resemble those of most mesophytic leaves, are surrounded by three or four rather small cells corresponding to subsidiary cells which can be easily distinguished from the larger, more irregular epidermal cells.

The wide-open pores on mature leaves average 18μ wide by 28μ long. The guard cells average 15μ larger in each dimension. *Verbena ciliata* and *Fouquieria splendens*, which Lloyd (1908) used in his investigations, have average pore openings of 10μ by 15μ and 9μ by 18μ , respectively. Eckerson (1908) reported the largest found in her observations as occurring on the upper surface of wheat leaves (grass type) 7μ by 40μ and those of *Chrysanthemum frutescens* (the common type) 11μ by 35μ . Pool and McKay (1916) reported those of alfalfa 3μ by 8μ . The large size of the stomata of patience dock is of decided advantage in making measurements of pores and micro-chemical tests of guard cell contents.

PART I

DIFFUSION OF WATER VAPOR THROUGH THE STOMATA

I DIFFUSION OF WATER VAPOR THROUGH SMALL OPENINGS

It has been known for some time that the exchange of gases and the loss of water from leaves occurs mainly through the stomata. The effect of variations in size of the pores on the rate of these processes is not as thoroughly understood. These experiments are confined to the loss of water vapor through the stomata since it is much easier to measure. The same principles of diffusion apply to all gases or vapors.

Brown and Escombe (1900) came to the conclusion that the static diffusion of gases through small openings is proportional to their diameters rather than to their areas. Table I confirms Brown and Escombe's results and shows very clearly that the diffusion of water vapor through small openings of this size in a thin septum is more nearly proportional to the diameters than to the areas of the openings. Since diameters and circumferences of circular openings are proportional it follows that diffusion is also proportional to the circumferences. It is possible to make two holes in a septum with the same circumferences or perimeters but with quite different shapes and areas,

in fact this is the case with the openings between the guard cells. When the guard cells are very wide open the pores are almost circular, but become elliptical and finally narrow slits as the guard cells close. If no changes in perimeter occurred on closing as much water vapor could diffuse through the pores when almost closed as when wide open according to this line of reasoning (neglecting the thickness of the septum).

Experiments were performed to see if Brown and Escombe's diameter law held when the shape of the hole was changed, but the perimeters remained the same. Two holes, one elliptical

TABLE 1

DIFFUSION OF WATER VAPOR THROUGH SMALL OPENINGS IN THIN CELLULOID SEPTA,
UNDER UNIFORM CONDITIONS

Diameter of Hole in mm	Diffusion of Water Vapor in grams	Ratios Areas of Holes	Relative Rate of Diffusion of Water Vapor	Ratios Diameter of Holes
2.64	2.655	1.00	1.00	1.00
1.60	1.583	.37	.59	.61
.95	.928	.13	.35	.36
.81	.782	.09	.29	.31
.72	.672	.07	.25	.27
.65	.590	.06	.22	.25
.56	.492	.05	.18	.21
.48	.455	.03	.17	.18
.41	.303	.02	.15	.15
.35	.364	.01	.14	.13

and one circular, were made in thin sheets of celluloid (Eastman Kodak Films) and the diffusion of water vapor through them was measured. Table 2 gives the results of these experiments which were repeated many times. Although these results do not agree as closely as those which illustrate the "diameter law," they do show that diffusion through an elliptical and a circular opening is more nearly proportional to the perimeters than to the areas of the openings. The elliptical opening has an area of only 14% of the circular opening, but there was 83% as much water vapor passed through the elliptical opening as through the circular opening under exactly identical conditions of temperature, humidity, etc. Exact agreement between perimeters could not be obtained although the experiments were repeated many times with different sized openings and under different conditions. In every case the results obtained showed quite

close agreement between perimeters but no relation to the areas of the openings

It should be noted that these results are not the same as those previously reported on this subject Stefan (1882) on theoretical grounds reported that the evaporation from a circular surface was almost the same as from an elliptical surface of the same area But these results indicate that evaporation from a circular surface would be more nearly equal to that from an elliptical surface having the same perimeter, not the same area. As far as could be found no one has ever tried to verify Stefan's deductions in their relation to diffusion through circular and elliptical openings in septa Brown and Escombe (1900) verified Stefan's deductions concerning the relation of diffusion through circular openings in a thin septa and found very

TABLE 2

DIFFUSION OF WATER VAPOR THROUGH ELLIPTICAL AND A CIRCULAR OPENING IN SEPTA AVERAGE OF 5 DETERMINATIONS WITH THE SAME SEPTA

Opening	Perimeter in mm	Area in sq. mm.	Diffusion of Water Vapor in gym	Perimeter	Ratios Diffusion
Circle	7.40	4.22	743	1.00	1.00
Ellipse	7.40	59	608	1.00	.83

close agreement between diameters and diffusion when the holes were smaller than 5 mm in diameter Thomas and Ferguson (1917) showed that for circular surfaces of 2 to 10 cm in radii that the evaporation is proportional to the (radius)^{1.5} when the vessels are full of water and not to the (radius)² as Stefan's theory demanded

In calculating the absorption of CO₂ and the loss of water through the stomata Brown and Escombe (1900) assumed that Stefan's deductions were correct and considered that the elliptical stomatal openings were equal to a circular opening of the same area in their diffusion capacity Renner (1910) followed Brown and Escombe's assumptions in his work Lloyd (1908), Livingston and Estabrook (1912), and Lottfield (1921) also made the same assumptions in expressing the diffusion capacity of the stomata. Livingston and Estabrook (1912) introduced the formula \sqrt{ab} to express the diffusion capacity of stomata, a and b being the major and minor semi-axes of

the elliptical opening This formula, \sqrt{ab} , is the radius of a circle whose equal area is to that of the elliptical opening, and is derived from the formula for the area of an ellipse But since the pores are not true ellipses and vary considerably from true ellipses especially when the stomata are almost closed the best representation of the diffusion capacity of the pores would be their average perimeters This can be measured easily with a small flexible rule from camera lucida drawings or photographs of the pores

In considering the diffusion of gasses through stomatal openings a "Perimeter Law," i e, variations in the rate of diffusion in proportion to the perimeter of the openings would more nearly represent the actual diffusion capacity of the stomata than Brown and Escombe's "Diameter Law "

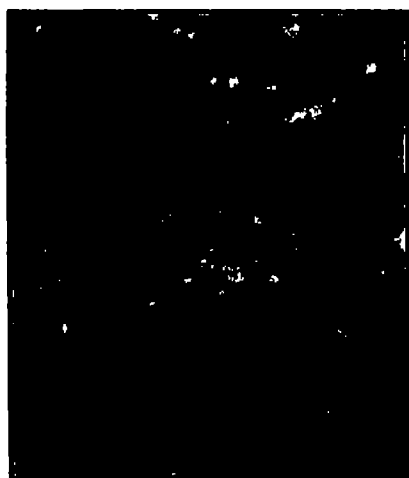


FIGURE 1

Photograph of the surface of an uninjured leaf of patience dock showing the stomata in position (About 90X)

II MEASUREMENTS OF PORE DIMENSIONS

The study of the size of the pores of the leaf was made by the second method suggested by Lloyd (1913) of direct observation in position on the uninjured leaf It is possible to see clearly and measure accurately or even photograph (see Figure 1) the stomata of patience dock because of their large size, with a lens having a 4 mm working distance and a 12.5 eyepiece An ordinary condenser and light from the northern sky, instead of

direct sunlight was used thus no injury to the leaf resulted from overheating. Careful checks were made and no injury to the leaf or change in the size of the pore resulted as reported by Loftfield (1921) even from repeated observations on the same place of a single leaf.

This method was chosen in preference to the absolute alcohol method also introduced by Lloyd (1908) and then later used by Loftfield (1921) because repeated checks always showed a narrower pore when the epidermis was removed and placed in absolute alcohol. Table 3 gives the results of a comparison of the two methods. Ten large pores were measured on the lower surface of the leaf and the epidermis from this same area was quickly removed and placed in absolute alcohol. Measurements were then made from the material in absolute alcohol.

TABLE 3

COMPARISON OF SIZE OF PORES IN POSITION ON THE UNINJURED LEAF WITH THOSE ON CUT AND STRIPPED PIECES OF EPIDERMIS WHEN PLACED IN DISTILLED WATER AND IN ABSOLUTE ALCOHOL. AVERAGE OF 20 PORES

Size of Pores	In Position on the Leaf	In Distilled Water		In Absolute Alcohol	
		Cut	Stripped	Cut	Stripped
in μ	12 x 33	3 x 33	14 x 29	3 x 29	7 x 28

A comparison of the results shows that caution must be used in the absolute alcohol method, because removing the epidermis from the leaf may change the size of the pores.

The average size of the stomata when they are wide open is 18μ by 28μ and the maximum is 20μ by 36μ . They vary from 37 per square millimeter on the lower surface at the base to 60 per square millimeter at the tip and from 26 to 38 per square millimeter on the same places on the upper surface of the mature leaf. Younger smaller leaves show more per unit area than the older larger ones. The average is 49 on the lower surface and 32 on the upper surface of the leaves. Comparing the elliptical opening to a circle having the same perimeter and assuming that they are spaced about equal distance apart, 32 stomata 18μ by 28μ which is the average size would be 9.3 diameters apart and 49 per square millimeter would be 7.2 diameters apart. Thus the stomata average 7.2 to 9.3 diameters apart on the leaves. According to Brown and Escombe's

results, there is little or no interference in diffusion between stomata when they are 8 to 10 diameters apart. That is, at or beyond this distance apart each stoma functions as a single opening.

From these results we can conclude that in patience dock each stoma acts practically as an independent unit. Any formula which would express the relation of the size of the pores to the rate of water loss through them should be derived from the linear dimensions of the pore and not from the area, since as shown by Table 2 the diffusion through elliptical openings is more nearly proportional to the perimeter than to the area. Variations in the perimeter of the pore, therefore, would more nearly represent the relation of the size of the pores to water loss through them.

III COMPARISON OF PORE DIMENSIONS

A comparison of perimeter, area, and width of the pores during opening and closing and the normal daily variations in these dimensions was made by direct observation on the uninjured leaves. Measurement of camera lucida drawings of the pores at different degrees of opening were also made. Much data were obtained from these studies, and since space is limited a summary only is included here.

Figure 2 shows the perimeter and area of the average pore (18μ by 28μ) at different stages of opening. These results are actual measurements of areas with a planimeter and perimeter with a flexible rule of camera lucida drawings of the pores at different degrees of opening. An examination of these curves shows that the area of the pore is about proportional to the width of the opening, but in the case of perimeter this is quite different. When the pore is open only 10% or 1.8μ in width the perimeter is 60% of the maximum. Thus, according to the diffusion law as applied to perimeters, the amount of water vapor which could diffuse through the pore when it is 10% open is 60% of the maximum, but since actual experiments have shown only an average of 83% as much diffusion through an elliptical as through a circular opening of the same perimeter we must modify this accordingly, so from actual physical experiments about 50% (83% of 60) of the maximum amount could diffuse through the narrow slit as compared to the wide

elliptical opening On closing, therefore, the rate of water loss through a stoma would decrease about 50% until the pore closed completely when the amount would be 0%

IV DAILY VARIATIONS IN PORE DIMENSIONS

Figure 3 shows the width, area, and perimeter of the pore during a 24-hour day Observations were made every hour as

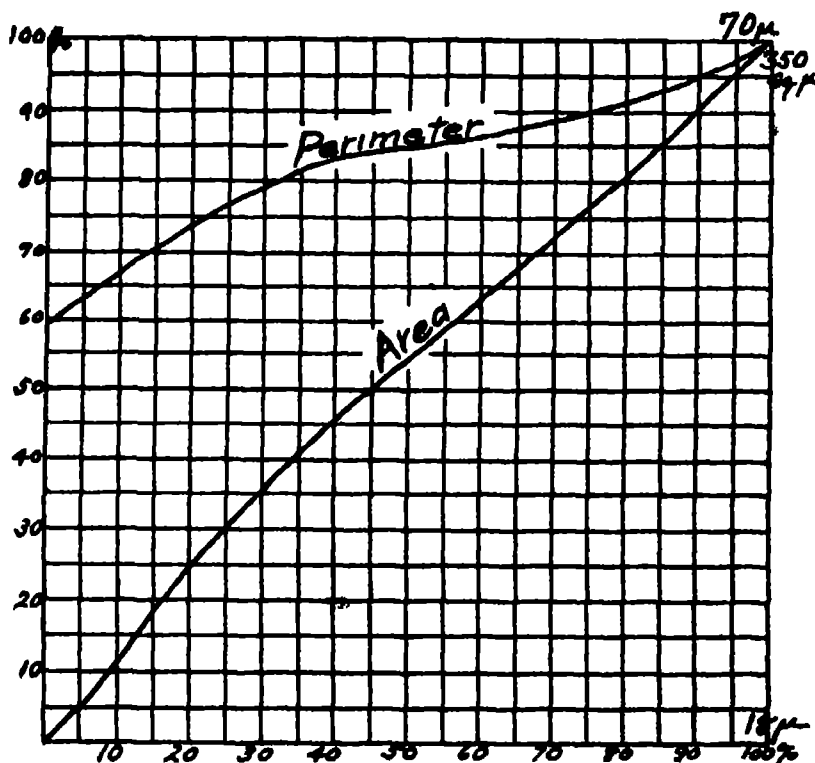


FIGURE 2

Perimeter and Area of the average pore ($18\mu \times 28\mu$)
at different stages of opening

long as the stomata were found open Records were made throughout the night, but the stomata of patience dock were never found open at night, even in bright moonlight. This is the opposite of their behavior as reported by Loftfield (1921) The first indication of opening occurs shortly after daylight in the morning and many may be found open at sunrise on a

bright morning On cloudy days opening is slower Figure 3 shows a gradual increase in width of the pores until a maximum was reached at about noon and then a gradual decrease in width until they were completely closed at sundown This is not the behavior that always occurs, however, for the degree of opening is influenced very much by environmental conditions, especially, humidity, the amount of water in the soil, and the temperature

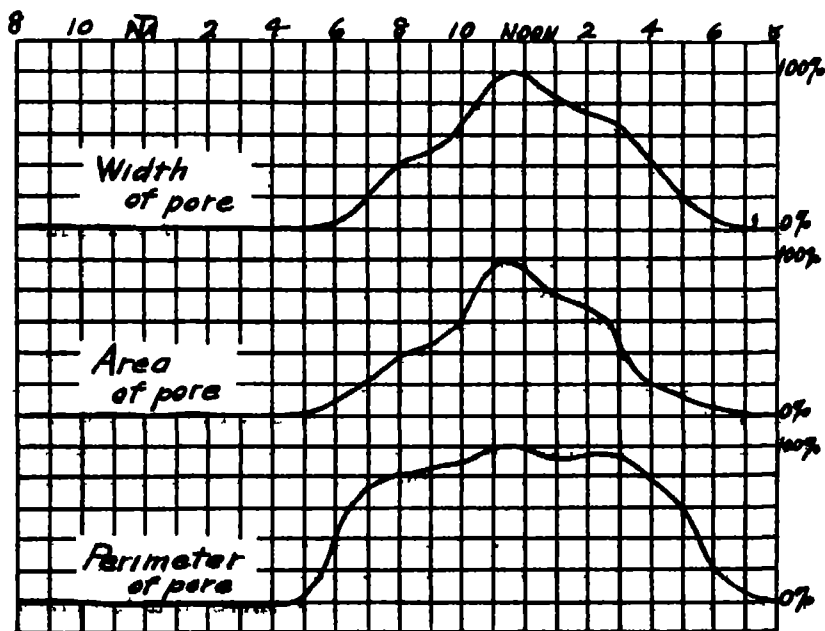


FIGURE 3

Daily variations in the width, area, and perimeter of the average pore ($18\mu \times 28\mu$)

On a bright clear warm morning maximum opening may be reached at 9 o'clock and if a favorable water balance is maintained throughout the day they may remain open until 5 o'clock in the afternoon. If the plant wilts slightly during the middle of the day closure results and opening may occur again in the late afternoon if wilting is not complete. If the plant is badly wilted they close and remain closed the rest of the day even in bright sunlight. Stomata on badly wilted plants which do not regain their turgidity at night do not open in the morning. No difference in the general behavior of the stomata on the two

surfaces of the leaf could be determined in all these observations Loftfield (1921) reported midday closure of the stomata of patience dock and other plants, also night opening under certain conditions, especially lack of water Although midday closure was very common, opening at night was never observed by the methods used in this work, even when the plants were not supplied with water until permanent wilting resulted

V BEHAVIOR OF STOMATA IN DARKNESS AND DURING WILTING

There are two other interesting facts in the behavior of the stomata of patience dock which were noted and carefully worked out in these investigations If a plant growing under normal conditions is placed in a dark box after sundown or late afternoon the stomata open at the usual time in the morning to 10-15% of their maximum width by the middle of the forenoon and close again by noon If the plant is kept continually in the dark this rhythm occurs noticeably the second morning, but not on the third or fourth day A similar behavior of stomata has been reported by others, but in most cases actual observations of the stomata were not made, but this behavior was inferred from the transpiration curve In patience dock there can be no doubt of this fact since the opening can easily be seen with a microscope

When the leaves of *Rumex patientia* are taken from the plant in a turgid condition with the stomata open the leaves wilt quite rapidly During this wilting there is a temporary opening of the stomata to a wider value in from 10 to 15 minutes after the leaf is taken from the plant, and then there is a closure of the stomata on the wilted leaf Wilting is noticeable a few minutes after the leaf is taken from the plant, but the stomata are not closed for 20-30 minutes Darwin (1898) reported this behavior in a number of plants with which he worked Laidlow and Knight (1916) by means of a recording porometer showed very clearly this behavior in *Phasolus vulgaris* Lloyd (1908) could find no indications of this temporary opening in his work

In patience dock this behavior is very easy to observe because of the large guard cells In position on the uninjured leaf 10 stomata averaged 10μ in width Six minutes after the leaf was cut from the plant 10 stomata from the same place on the leaf averaged 17μ in width and 5 minutes later, 18.4μ In 28 minutes after the leaf was cut from the plant all the stomata were closed

If on the other hand the leaf is attached quickly to the water tap instead of allowing it to wilt, and water is forced into the leaf under a pressure of about 3 atmospheres the opposite behavior results, the stomata close immediately to about 10% of their maximum width. If the pressure is removed so that the intercellular spaces do not fill with water the stomata will return to their former opening and on wilting they will close. These observations substantiate the fact that in general light is the most important factor concerned in opening and closing of stomata but that the amount of water in the leaves also may modify the degree of opening very markedly.

VI RELATION OF STOMATA TO WATER LOSS FROM THE LEAVES

That the loss of water from the leaves occurs mainly through the stomata has been proven by numerous investigators, but the modifications of the rate due to variations in the size of the pore is not as clearly understood. That complete closure of the stomata stops water loss from the intercellular spaces of the leaf can not be doubted, but some investigators seem to doubt if complete closure ever occurs. In these investigations an attempt was made to solve these two problems as far as the water loss from patience dock is concerned. Two methods of measuring water loss from the leaves were used. Direct weighing of the plant which necessitated sealing in a pot and thus limiting the root system, and the cobalt chloride method of comparing the rate of water lost from a free water surface with that from the leaves of the plant. In this method plants growing in the soil can be used.

Figure 4 shows the hourly rates of water loss from the plant and evaporation from a porous cup under similar environmental conditions. These data were obtained by weighing a sealed potted plant and an atmometer at hour intervals throughout the day. The environmental factors were recorded by automatic recording instruments. The transpiration curve shows that there is a periodic water loss from the plant, a very low constant rate during the hours of darkness with a very high rate during the day. The curve of water loss from the porous cup is very similar to the transpiration curve and one might think at first that the periodicity of water loss from the plant is due simply to the increased "evaporating power" of the air. But a careful examination of the data shows that this is not true. When the

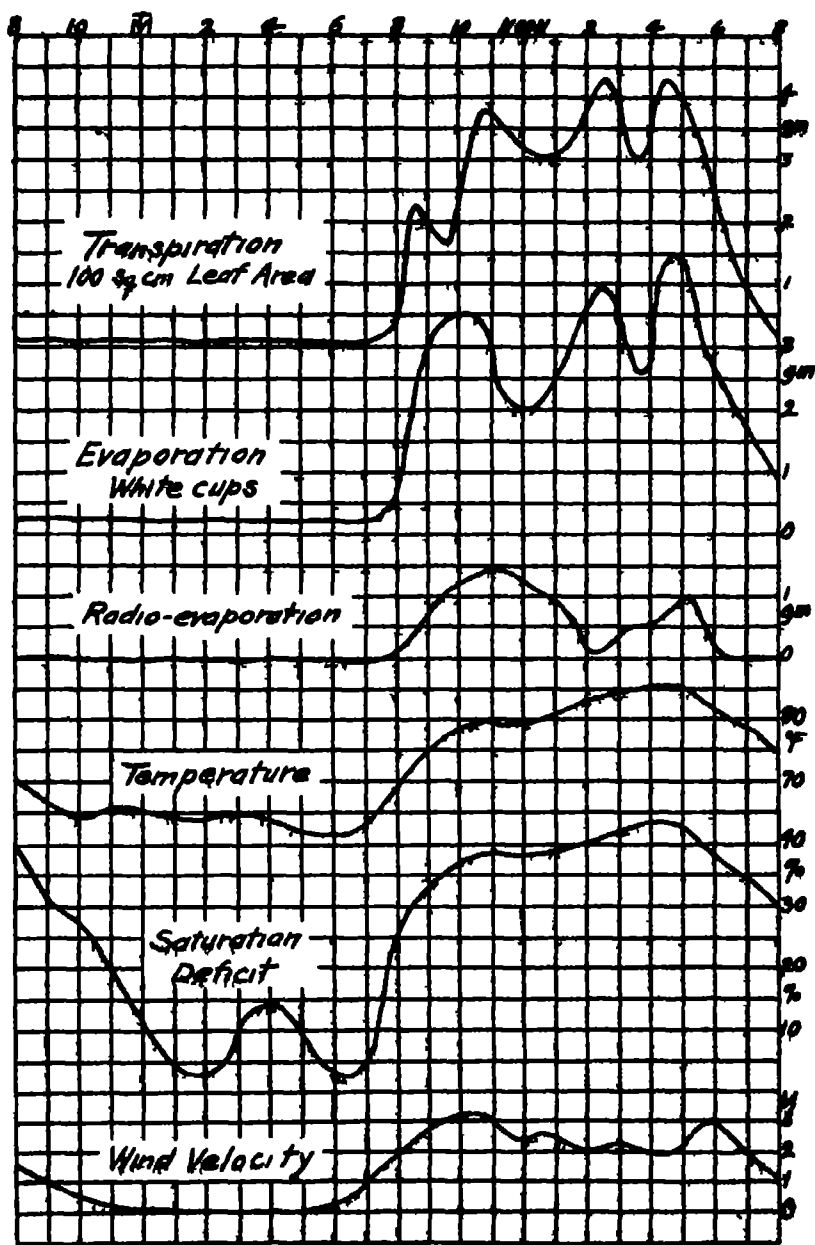


FIGURE 4

Comparison between transpiration and environmental factors

average hourly night rates of evaporation and transpiration are compared with the same values for the day it is seen that although the increase of day over night rate is considerable in each case the rate of water loss from the plant has increased many times more than the rate of evaporation. Table 4 shows a comparison of the data given in Figure 4 made in this way. The average day rate of transpiration was 51 times greater than the average night rate, while evaporation has increased only 17 times. Even in the case of blackend cups, which absorb heat energy to a greater degree than the green leaves and be at a temperature slightly higher than the air, the increase was only 19 times. Since the same environmental factors tend to increase both processes and are the same in each case, the conclusion is

TABLE 4
AVERAGE DAY AND NIGHT RATES OF TRANSPIRATION AND EVAPORATION UNDER
SIMILAR ENVIRONMENTAL CONDITIONS

	Grams per Hour		Increase Day Rate Over Night Rate
	Average Day	Average Night	
Transpiration	2.81	0.55	51 times
Evaporation			
White cups	2.88	1.63	17 times
Black cups	3.21	1.63	19 times

obvious that some factor in the plant causes the added increase of day over night rate. When the data for Figure 4 was obtained the air was almost saturated at night with no wind and the following day was clear, hot, with quite variable wind velocities, thus presenting almost two extremes in environmental factors. A similar set of data was obtained in the winter in the greenhouse, where the environmental factors between day and night were more uniform. Wind was eliminated from the experiment in the greenhouse. The increase of day over night rate in this case is not as great. Transpiration in this experiment increased 9.7 times, while evaporation increased only 3 times. In both experiments transpiration has increased about three times as much as evaporation.

There are several possible causes of this periodicity of water loss from the leaves, variations in amount of water in the leaves, changes in the osmotic concentration of the mesophyll

cells changes in H ion concentration of the mesophyll cells and opening and complete closure of the stomata thus shutting off water loss entirely from the intercellular surface of the leaf

The amount of water in the leaves was found by drying at 104° C to constant weight leaves without the petioles or mid ribs in glass stoppered weighing bottles The average amount of water in the leaves at night when they are turgid and crisp was 90.95% There was no decrease in this amount until about 10.30 in the forenoon when the amount had decreased to 89.3% in one of the experiments There was a gradual decrease from that time until between 3-4 P M when the minimum of 88.8% was reached Although the leaves were still erect they were

TABLE 5
OSMOTIC VALUE AND pH VALUE OF THE JUICE PRESSED
FROM THE FROZEN LEAVES OF PATIENCE DOCK

June 26	Osmotic Value n Atmo	pH Value of the Juice
8 A M	9.26	3.9
10 A M	9.40	3.8
12 Noon	9.65	3.8
2 P M	9.95	3.8
4 P M	9.86	3.8
6 P M	9.39	3.8
8 P M	9.23	4.0

noticeably flaccid and not as crisp as at night when they contain the maximum amount of water The amount increased after 4 P M until at 9 P M the maximum amount was present again Livingston and Brown (1912) reported a decrease in leaf water content of about 2% in the plants with which they worked Knight (1922) also reported about the same decrease In neither case were the leaves wilted Under ordinary conditions there is a daily variation of about 2% in leaf water content of the leaves of patience dock

Table 5 gives the osmotic pressure in atmospheres and the pH value of the sap pressed from the leaves (without midribs) at 2 hour intervals during the day The leaves were frozen the sap pressed out and the depression of the freezing point determined with a Beckman thermometer The pH values were determined by the colorimetric method of Clark (1920) Freezing caused no change in pH value of the sap as checks

with frozen and unfrozen tissue showed the same value. Determinations in the depression of the freezing point at night showed no further decrease in the values. This table shows that there is an increase in the osmotic value of the sap during the day reaching a maximum at about the same time the leaf water content reaches a minimum. The H-ion concentration fluctuated between pH 3.8–4.0, but with no consistent variations which would indicate that there was a daily change in the pH value. These variations are within the limit of error of the method used.

The decrease in leaf water content and increase in osmotic concentration during the day would tend to decrease the rate of water loss from the leaves. But these factors appear to have no very decided effect on the rate of water loss because it is greatest when these factors would tend to reduce the amount. Changes in acidity alter the hydration of colloids, but no consistent change occurs in the leaves of patience dock, so the only internal condition left to consider which would cause such a large increase of day over night rate is the opening and complete closure of the stomata.

Observations on the stomata of the uninjured leaves showed that they were always closed at night. No exception to this rule was found. They were always found open in the daytime if the leaves had not wilted. On wilted leaves they were often found closed or almost closed, depending on how long wilting had been evident. But the objection has been raised that closure which appears complete under a microscope does not mean hermetically sealing so that no water vapor can escape through them.

An experiment was performed which shows that the stomata of patience dock are closed tight at night so that water vapor does not diffuse through them. Two similar plants were taken, one placed in a dark box and the other on a table beside it. The following day the time required for standard cobalt chloride paper to change from blue to pink on similar leaves of each plant was determined. Cobalt chloride paper from the same sheet was taken for the test and both plants were at the same temperature so the results are comparable. An examination of the plants just before the tests were made showed that the stomata on the plant in the light were open, while those in the dark were closed. The paper changed to red in one minute and 40 seconds on the lower surface of the leaf with open stomata,

while 75 to 80 minutes were required to produce the same color change on the leaf with closed stomata. Assuming that the rate of water loss is proportional to the time of color change, water is lost from the leaf with open stomata 45 times as fast as when the stomata are closed. Since according to the "diameter law" modified to include elliptical openings, any preceptible opening between the guard cells would allow 50% of the maximum rate of water loss it is safe to conclude that no water vapor is lost through the stomata when they are closed. The change in the cobalt chloride paper on the leaf with closed stomata represents the rate of water loss from the epidermis,

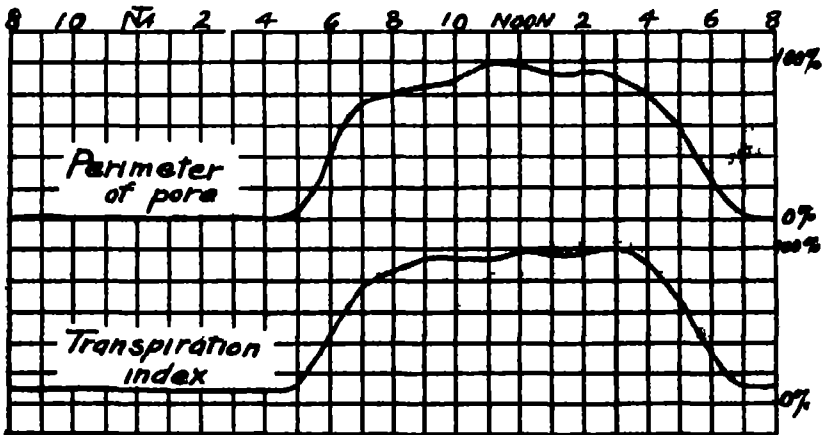


FIGURE 5

Comparison between transpiration index and perimeter of the stomata

since very similar results are obtained from test on leaves with stomata only on one surface. In Vinca where the stomata occur only on the lower surface, the same cobalt chloride paper turned red in 2 minutes when the stomata were open, but 60 to 70 minutes were required for the same change under the same conditions on the upper surface of the leaf.

The most important cause of the periodicity of water loss from the leaves of patience dock is the opening and complete closure of the stomata. At night when the stomata are closed, there is a very low constant rate because the environmental factors on which this epidermal water loss depends are very constant. But during the day when the stomata are open, the rate is very high and quite variable from time to time. This is

due to the fact that the factors on which the rate depends are many and are apt to vary considerable. Environmental factors are usually more variable during the day than at night. The internal factors are also quite variable and some tend to increase the rate, while others tend to decrease it and no single factors can be found on which the rate depends entirely. An examination of the general shape of the curve of water loss during the day, however, will show that it more nearly corresponds in its main outline to the curve for average perimeter of the stomata.

When the curve of transpiration index determined by the cobalt chloride method is compared with the curve for perimeter of the stomata there is still closer agreement between them. Figure 5 gives the curve for transpiration index and perimeter of the stomata. These data are the average of a number of determinations of the time of color change of standard cobalt chloride at each hour and for the same place on each leaf along with the average size of the pores on those same areas of the leaves. The curve of transpiration index and perimeter of the stomata are almost the same because in this method of measuring the relative water loss all environmental factors are eliminated. Thus the curve of the transpiration index would be more nearly a curve of the function of the stomata. This curve does not indicate the actual rate of water loss from a plant under ordinary conditions. When the cobalt chloride paper is placed on the leaf air currents are absent and there is a layer of dry air next to the leaf, since the cobalt chloride paper is perfectly dry when used. It is equivalent to measuring water loss from a plant surrounded by perfectly dry still air.

These variations in the day rate of water loss as shown by Figure 4 are due mainly to differences in temperature, humidity, wind velocity, (caused by cloudiness), and leaf water content, the main shape of the curve being due to the opening and closing of the stomata.

VII SUMMARY

Patience dock was selected for this study of the physiology of the stomata because of the very large guard cells. The leaves are large and smooth and the plant grows well under ordinary conditions. The epidermis can be easily removed so that the guard cells can be studied under varying conditions.

Brown and Escombe's laws of diffusion of gases through small openings were checked and were further shown to apply to elliptical openings.

Checks on the methods of measuring the dimensions of the pores were made and the method of measuring the pores on the uninjured leaf was chosen because of the variations shown when the epidermis was removed from the leaf. A comparison of the area, perimeter and width of the pore during opening and closure was made. The width of the pore is the best means of expressing the degree of opening of the stomata.

When the dimensions of the pores were measured during the day and under different environmental conditions considerable variations were found. It was necessary to average a number of measurements in order to have comparable results. A rhythm of the opening of the stomata was observed in darkness after a day in light and a temporary increase in the width of the pore was noted when permanent wilting began.

In a study of the relation of stomata to transpiration the effect of complete closure of the stomata was determined and an attempt was made to correlate the variation in the pore dimensions with the rate of transpiration from the leaves.

PART II.

PHYSIOLOGY OF THE GUARD CELLS

I OSMOTIC RELATIONS OF THE GUARD CELLS

Since the time of Von Mohl, 1856, the opening and closing of the stomata has been explained by changes in turgor of the guard cells, but few investigators have made direct measurements of this turgor. Iljin (1914) was the first to attempt a measure of the pressure within the guard cells and the epidermal cells. He reported the average osmotic value of the guard cells to be 90-100 atmospheres when open, while the epidermal and mesophyll cells were about 20 atmospheres. His determinations were made by the plasmolytic method using KNO_3 in different concentrations as a plasmolysing solution. Wiggins (1921) using CaCl_2 as a plasmolysing solution, determined the osmotic value of the guard cells of *Zebrina pendula*, *Cyclamen*, *Iresine*, and sugar beet. He found a higher pressure in the guard cells than the surrounding cells when the stomata were open, but his

results were very lower than those obtained by Iljin (1914), the difference between guard cells and epidermal cells averaging about 13 atmospheres

The method of determining the osmotic value of the guard cells of patience dock in this work was the usual plasmolytic method, taking as the osmotic value of the cells that concentration in which the cell contents showed the first indications of shrinkage away from the cell wall. Two methods of applying the different concentrations of the plasmolysing solution were used. In the first method small pieces of the tissue were placed in about 1 cc of the different concentrations in a small vial and examined after 2-5 minutes in a drop of that solution on a slide under a microscope. In the second method a small piece of tissue was placed across a narrow groove in a slide, covered with a cover glass and the different concentrations of the plasmolysing solutions were drawn through under the cover glass with a filter pump. From 1 to 2 cc of the different solutions were used and allowed to remain in contact with the tissue from 1-2 minutes or until no further change occurred in any of the cells. The two methods gave very similar results in all checks. The last method has the advantage of requiring less material and of permitting continuous observations on a single group of cells. The uniformity of the results obtained by these two procedures indicated that the method is as accurate as any other of the plasmolytic methods. The results are usually too high because of some cell shrinkage before the protoplasm pulls away from the cell walls. Knudson and Ginsburg (1921) showed that if the tissue is properly frozen and high pressures are used in extracting the juice that the freezing point method and the plasmolytic method gave very similar results.

All solutions used were standardized by the depression of the freezing point method and the results are expressed in atmospheres. Glucose, cane, sugar, CaCl_2 , and KNO_3 were used in order to eliminate, if possible, differences in permeability of the guard cells. The osmotic value of 1M, 2M, etc., concentrations of the solutions were determined and a curve of the values plotted from which pressures of any desired concentration could be read. Dilutions of the stock solutions were made having values of from 1.2 to 2.5 atmospheres, depending on the substance used. Records of pore dimensions and

environmental factors were obtained for each period that osmotic values were made

Such wide ranges of variations in the osmotic values were found that it was necessary to observe from 30 to 40 guard cells

TABLE 6

OSMOTIC VALUE IN ATMOSPHERES OF THE GUARD CELLS, SUBSIDIARY CELLS, AND EPIDERMAL CELLS, USING DIFFERENT PLASMOLYSING SOLUTIONS

Time August 2, 1921	8.30 A M	10.30 A M	1.30 P M	3.30 P M	7.30 P M	
Stomata	3x30	6x31	12x24	9x31	0x0	Microns
Guard Cells Maximum	19.1	17.8	23.0	21.4	14.4	Cane sugar
Guard Cells Average	16.6	16.6	21.0	20.2	13.2	
Subsidiary cells	16.6	16.6	16.6	17.8	15.5	
Epidermal cells	14.4	14.4	14.4	14.4	13.2	
Guard Cells Maximum	16.2	16.2	19.6	17.8	14.0	Glucose
Guard Cells Average	15.1	15.5	17.3	16.6	12.9	
Subsidiary Cells	16.2	15.1	16.2	16.6	15.1	
Epidermal Cells	14.0	14.0	14.0	15.1	12.9	
Guard Cells Maximum	18.4	18.4	21.9	20.0	12.4	CaCl ₂
Guard Cells Average	17.5	17.5	18.4	18.4	12.4	
Subsidiary Cells	14.8	15.7	15.7	15.7	13.0	
Epidermal Cells	13.0	14.2	13.0	14.2	12.4	
Guard Cells Maximum	19.8	?	?	?	13.8	KNO ₃
Guard Cells Average	15.1	?	?	?	11.8	
Subsidiary Cells	14.0	15.1	16.2	15.1	10.4	
Epidermal Cells	10.4	10.4	11.8	11.8	10.4	

to obtain average results which were comparable. The average values of the subsidiary cells, and epidermal cells were noted and the average and maximum values of the guard cells were determined. Because of the fact that pieces of the epidermis were cut and placed in water before starting the determinations it was impossible to measure the size of the openings of individ-

ual stomata and their osmotic value The pore dimensions are the average values from the same areas of the leaf before the epidermis was removed

Table 6 shows the osmotic values in atmospheres of the guard cells, subsidiary cells, and epidermal cells, with average pore dimensions from the upper epidermis of leaves of patience dock Marked differences between some of the values in this table are shown These differences are due, no doubt, to the difficulties encountered such as distinguishing between the effect of a solution of 15 atmospheres and one of 16.5 atmospheres, variation in individual leaves and plants due to age, water supply, light, etc., since it is impossible to use the same piece of epidermis for more than one determination

The results shown when glucose, cane sugar, and CaCl_2 are used are quite similar, but those obtained from KNO_3 are not consistent The highest concentration of KNO_3 used, 27 atmospheres, failed to show any indications of plasmolysis when the stomata were wide open A test of the permeability of the guard cells to the different substances showed that when open the guard cells of patience dock were readily permeable to KNO_3 This suggests an explanation of the high values reported by Iljin (1914) when only KNO_3 was used These results agree quite closely with those reported by Wiggins (1921) The osmotic value of the epidermal cells are quite constant throughout the day, the variation being due to differences in material or experimental errors rather than real differences in concentration The average value is about 13 atmospheres The subsidiary cells show similar variations but are always higher, averaging about 15 atmospheres The guard cells show values when they are closed below the subsidiary and about equal to the epidermal cells, but much higher values when they are opened The maximum value was as high as 23 atmospheres when fully opened, but averaged 19 atmospheres Values as high as 27 atmospheres were noted in some of the trials The osmotic values when the stomata were closed at night were carefully checked and the results showed that the guard cells were 1 to 2 atmospheres lower than the subsidiary cells Thus the guard cells were actually pressed together at night when they are closed

Figure 6 shows the results of a similar experiment on the guard cells and the surrounding cells of patience dock using only cane sugar as the plasmolysing solutions The results

are expressed graphically and show the average pore dimensions from the same leaf that the pieces of epidermis for the tests were taken. The same general results as described in Table 6 were obtained. Many other measurements were made on the osmotic values of the guard cells, but space does not permit the presentation of all these data. These data showed that there was no appreciable difference between the osmotic value of guard cells on either surface of the leaf, and that the average

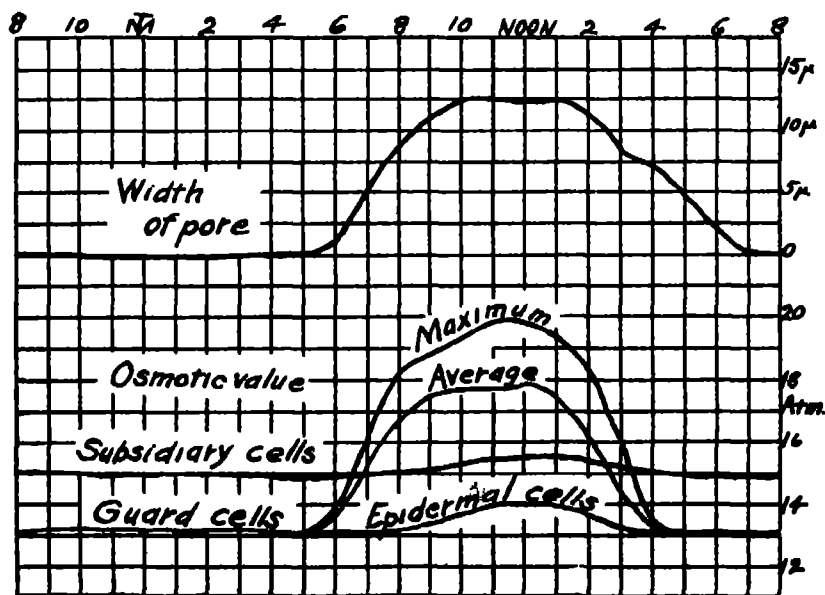


FIGURE 6

Comparison between the osmotic value of the guard cells and the width of the stomata.

pore dimensions do not always correspond very closely with the average osmotic values of the guard cells. The midday closure reported by Loftfield (1921) was noticed in many cases, but no change in osmotic values could be found that was correlated with this closure unless the closure was complete, as in badly wilted leaves. There was no increase in osmotic pressure in the guard cells corresponding to the temporary opening just before wilting, but when the stomata closed on permanent wilting there was a decrease in osmotic value of the guard cells.

As is shown in Table 3, there is a partial closure of the stomata when sections of the epidermis and mesophyll are cut and placed in distilled water, but when the epidermis is stripped and placed in water the guard cells open wide. When these cut sections with the stomata partly closed are subjected to successively stronger plasmolysing solutions and the guard cells carefully observed, it is seen that the guard cells gradually open as the solution approaches the osmotic value of the epidermal cells, then as stronger solutions are added the guard cells close, and finally are plasmolysed. This behavior as well as midday closure and temporary opening on wilting, seems to be due to turgor changes in the surrounding cells as no corresponding changes in osmotic values of the guard cells were found which accounted for them.

It will be noted from Table 5 that the osmotic value of the mesophyll cells determined by the depression of the freezing point of frozen expressed juice was about 2-3 atmospheres lower than the values of the epidermal cells obtained by plasmolysis. It was impossible to see plasmolysis in the mesophyll cells in those sections used for the determination of guard cells. This would have been very desirable for a more accurate comparison. Iljin (1914) reported the mesophyll cells and the epidermal cells to have similar values. The difference in these results is probably due to the difference in methods of determination, since no powerful press was used to extract the juice from the frozen leaves and thus the values would be somewhat lower than those determined by plasmolysis. It was found that the osmotic values of all the cells of the different tissues of the leaf were from 2-3 atmospheres lower when the plants were growing in the greenhouse during the winter than when the plants were in the soil out of doors.

In conclusion it can be said that the increase and decrease in the osmotic value of the guard cells is the main cause of their opening and closing, but that osmotic pressure alone does not account for all their movements or changes in dimensions.

II STARCH AND SUGAR CONTENT OF THE GUARD CELLS

Darwin (1898) reported a change in the starch contents of the plastids of the guard cells during opening of the stomata. Lloyd (1908) proved that starch disappears from the plastids of the guard cells of *Verbena ciliata* and *Fouquieria splendens*.

when they open Iljin (1914) and Loftfield (1921) and Weber (1924) also reported the same observations In patience dock the same change in starch content of the guard cells occurs

In spite of the fact that Lloyd (1908) showed very clearly that the starch content of the guard cells decreased when the stomata open and thus their opening was not due to photosynthesis since in photosynthesis starch usually accumulates in plastids, many people still explain the behavior of the guard cells on this basis The reason for this is due to their misconception about the plastids of the guard cells, which on casual examination appear to be chloroplasts But a careful examination and consideration shows that they are quite different than the chloroplasts of the mesophyll In patience dock the chloroplasts of the leaf are $5-6\mu$ in diameter, appear as single structures and do not vary in size with their starch content The plastids of the guard cells have at the maximum size a diameter of only 4μ , appear as compound structures, and vary in size with their starch content The starch in both the plastids of the guard cells and the mesophyll cells does not show a cross with polarized light, thus indicating a colloidal form similar to starch paste rather than starch grains Chlorophyll develops in the chloroplasts when exposed to light only, while the green color of the guard cells is shown under any conditions The green color in the plastids of the guard cells does not give the micro-chemical tests for chlorophyll, but there is no conclusive proof that it is not chlorophyll because of the extreme difficulty of making the test on such small bodies The green color of the plastids of the guard cells does not disappear in continued darkness while that in the chloroplasts does The most striking difference, however, is in the occurrence of starch in the two structures Starch is found in chloroplasts only in light and soon disappears in continued darkness Some leaves as banana, lettuce, and onion, and probably many more, never show starch in the chloroplasts at all Starch occurs in the guard cells of all plants examined under any condition where the guard cells are completely formed even in plants grown from seed in complete darkness, in white areas of variegated leaves, white shoots of plants, albino corn, etc Onion is the only plant examined which did not show starch in the guard cells Thus it can be easily seen that the plastids of the guard cells are different structurally, physiologically, and genetically, from the chloroplasts of the mesophyll cells

The iodine method was used in measuring the starch content of the guard cells in this work. The amount of starch present by this method cannot be expressed in percentages because the test shows only a difference in the density of the blue color. Very slight differences, however, can be detected if two pieces of epidermis are mounted side by side after staining with iodine so that half the field of the microscope will be occupied by each piece. The results of these tests are expressed in four estimates, no change, very slight change, moderate change, and very striking change. They refer to an increase or a decrease in the

TABLE 7

STARCH CONTENT, OSMOTIC VALUE, AND PORE DIMENSIONS OF THE GUARD CELLS FROM THE LOWER EPIDERMIS OF PATIENCE DOCK

Time and Date	Pore Opening μ	Osmotic Value Atmo	Starch Content
Aug 4			
7 30 A M	9 x 31	16.6	Starch present
9 00 A M	11 x 32	17.5	Moderate decrease
11 15 A M	5 x 30	15.7	Slight increase
12 45 P M	3 x 29	13.9	No change
4 00 P M	6 x 29	13.9	No change
7 30 P M	0 x 0	12.2	Slight increase
Aug 5			
8 00 A M	5 x 30	14.8	Moderate decrease
9 00 A M	9 x 31	15.7	Moderate decrease
10 00 A M	7 x 30	15.7	No change
12 00 Noon	6 x 28	16.0	Slight increase
2 00 P M	16 x 34	16.6	No change
4 00 P M	13 x 32	14.8	Slight increase
6 00 P M	0 x 0	12.2	Slight increase

starch content of a given specimen when compared with another specimen taken at some other time. Specimens were obtained for every hour of the day, kept in alcohol, which removed the chlorophyll and stained with iodine when examined. Table 7 gives the starch changes of the guard cells from the lower epidermis of patience dock together with the pore dimensions and osmotic values (CaCl₂ used as plasmolysing solution).

This table shows that there is a decrease in the starch content of the guard cells in the early forenoon which is correlated with the rise in osmotic values and increase in pore dimensions. On August 5 there occurred midday closure (partial) but there was no corresponding decrease in osmotic value or increase in starch content.

Lloyd (1908) pointed out that this fluctuation in starch content in the guard cells is just the opposite of that which occurs in the mesophyll cells of the leaf. An experiment extending over parts of two days was performed to show this variation. The width of the pore opening, starch content of the mesophyll cells and guard cells were determined by the methods previously described and are tabulated in Table 8. Starch increase in the mesophyll cells in the forenoon and reaches a maximum later in the day. But in the guard cells the starch content decreases in the forenoon when the mesophyll cells show an increase.

TABLE 8
COMPARISON OF STARCH CONTENT OF THE GUARD CELLS AND
MESOPHYLL CELLS OF PATIENCE DOCK

Time and Date	Pore Width μ	Starch Content Guard Cells	Starch Content Mesophyll
March 13, '22			
7:00 A M	2	Starch present	Starch present
9:00 A M	11	Moderate decrease	Slight increase
11:00 A M	16	Moderate decrease	Slight increase
1:00 P M	17	Slight increase	Slight increase
3:00 P M	11	No change	Slight increase
5:00 P M	1	Moderate increase	No change
7:00 P M	0	Slight increase	Slight decrease
9:00 P M	0	No change	Slight decrease
March 14 '22			
7:30 A M	2	Moderate decrease	Decided decrease
9:00 A M	6	Moderate decrease	No change
11:00 A M	9	No change	Slight increase

The minimum occurs sometime before noon as Lloyd (1908) has shown in his work. There are slight fluctuations during the rest of the day with an increase again at night to the same amount as was present very early in the morning. No changes in the starch content of the guard cells during the hours of darkness could be detected. In the mesophyll cells, however, there is a gradual decrease during the night. Young rapidly growing leaves contain no starch by morning.

The decrease in starch content of the guard cells in the morning indicates that the rise in osmotic value is not due to photosynthesis. This is further proved by the behavior of guard cells in CO_2 free air. Lloyd (1908) found normal behavior of stomata in CO_2 free air. Patience dock showed normal opening and closure for four days in CO_2 free air. After the first day no

starch was found in the mesophyll and as the plant showed signs of starving the fourth day, the experiment was ended

None of the investigators who studied starch fluctuations in the guard cells have attempted to show that sugars were present. They have assumed that if starch disappears sugar increases because of the usual reciprocal relation between the two and because the osmotic value rises when the starch content decreases. Micro-chemical tests for the presence of reducing sugars in the guard cells of *Rumex patientia* were made as follows: a small quantity of copper tartrate was mixed with 15% NaOH and a drop of this mixture placed on a slide, a piece of epidermis was placed in this mixture, a cover glass was added, and the slide was heated at 96° C for 5 minutes. Equal sized pieces of epidermis were used and the same concentration of Copper solution was used, (mixed fresh before each test), so that the results are comparable. The sugar content of the guard cells was determined by estimating the number of copper oxide crystals formed which under identical test conditions showed from 2 to 2½ times as many when the guard cells were open as when they were closed.

We can conclude so far from this study of the physiology of the guard cells that the principal cause of the opening and closing of the guard cells is a change of the starch in the plastids of the guard cells to sugar which raises their osmotic value.

III EFFECT OF CHANGES IN ACIDITY ON THE STARCH AND SUGAR CONTENT OF THE GUARD CELLS

After the foregoing conclusions were obtained investigations were started to attempt to find out the cause of the change from starch to sugar in the guard cells. The reaction seems to be a reversible one in which the total amount of carbohydrate material does not vary, but is simply changed from one form to another under certain conditions. Since such changes in plants appear to be activated by enzymes the explanation of the change would be some condition which favors the action of the enzymes. The synthetic action of enzymes is inferred from the occurrence of compounds in the plant and little is known of the conditions under which they occur. But the hydrolytic action is easily demonstrated and much is known of the conditions favorable for this reaction. The H-ion concentration of the medium is important in the hydrolytic action of enzymes, there is an

optimum, a maximum, and a minimum value at which the reaction occurs

All attempts to isolate enzymes from the guard cells failed because it was impossible to collect enough material to give a solution of sufficient concentration for a study of their reactions. But observations on the guard cells in different plasmolysing and buffer solutions furnished an explanation of the conditions favorable for the action of these enzymes. When the acidity of the guard cells was determined colorometrically by the use of Clark's indicators, it was found that the guard cells were slightly more alkaline with Bromphenol blue when they were opened than when they were closed. But it was impossible to determine the pH values because of no accurate means of color comparison under the microscope.

Attempts were made to find a buffer solution in which the guard cells would remain alive so that the effect of different H-ion concentrations could be studied. The phthalate buffers of Clark (1920) proved very toxic to the guard cells, the protoplasm appeared to be precipitated or coagulated when the guard cells were placed in this solution for an hour or more. Solutions of potassium oxalate and potassium phosphate were not as toxic as the phthalate solution, but it was difficult to make a balanced solution from these of a required H-ion concentration. Some results were obtained with these solutions, however, and will be mentioned later. The best results were obtained by using the juice from the leaves of the plant, patience dock, as a buffer solution. The juice was pressed from the leaves and dialysed with an equal volume of distilled water. This produced a clear liquid of pH value 3.8-3.9 and osmotic value of about 4 atmospheres. Guard cells appeared normal after 36 hours in this solution, no coagulation or precipitation of the protoplasm resulted. The pH value of this juice was adjusted to any desired value by adding small quantities of dilute HCL or NaOH.

When the guard cells were closed and were placed in this juice which was adjusted to pH values of 3.6-3.8-4.0, etc., to 5.0, they remained closed in the pH 3.6-3.8-4.0 solution, also in the pH 4.6-4.8-5.0 solution, but opened after 2 hours in the solution of pH 4.2-4.4. When the opened guard cells were placed in a series of these solutions they closed in all except the pH 4.2-4.4 after 2 hours or more. These tests were repeated many times and similar results were obtained each time. The

pH value of each solution was tested before and after it was used

Similar experiments were conducted using phosphate buffers, oxalate buffers and various nutrient solution all adjusted as near as possible to the same series of pH values. Similar results were obtained in all the tests, but they were not as consistent and the guard cells did not open as wide or remain opened as long as in the dialysed juice. The optimum opening, however, occurred at about the same place in all cases, pH 4.2-4.4

Determinations of the osmotic value of the guard cells and their starch and sugar content showed that when this opening occurred in the dialysed juice there was an increase in osmotic value and sugar content and a decrease in starch content. When closing occurred the opposite results were observed. Since this opening and closing of the stomata in the dialysed juice appeared to be just like that which occurs normally on the uninjured leaf the theory is advanced that changes in acidity are the cause of the starch to sugar changes in the guard cells.

Since these experiments were completed Weber (1923) has published his results on the effect of different ions on the guard cells. He found that Na- and K-ions favored the change of starch to sugar, while Ca-ions favor the change of sugar to starch. While determining the osmotic value of the guard cells of patience dock it was noticed that the starch content of guard cells which were plasmolysed several times with CaCl_2 increased considerably. But the same thing happened when cane sugar or glucose were used as the plasmolysing solutions, so it did not seem to be due to the Ca-ion. The concentration of the salt ion in the dialysed juice was not changed materially by the addition of small quantities of HCL or NaOH as were required to produce the desired change. The only factor which is changed in the series of buffers of the dialysed juice is the H-ion concentration, and as the guard cells open in these different concentrations it appears to be due to the change in H-ion concentration.

There is some further evidence to support this conclusion. The effect of acid and alkaline atmospheres on the guard cells was determined by the methods used by Small (1920) in the geotropic response of roots. Leaves with the stomata opened were placed in containers with varying amounts of dilute ammonia and acetic acid and the guard cells were studied. Opening to 50% of maximum occurred after 3-5 hours in ammonia vapor in darkness, but no opening occurred in acetic

acid vapor. Closure of opened stomata occurred in acid atmosphere in light, but not in alkaline atmosphere. Since it was necessary to enclose the leaf in a tight thick glass chamber it was not conclusive proof whether acid atmosphere or lack of light caused the closure. Over heating occurred if the containers were placed in full sunlight. These observations seem to further indicate that changes in acidity of the guard cells are the cause of the sugar to starch, or starch to sugar changes which result in their opening or closing.

IV PROBABLE CAUSE OF THE CHANGES IN ACIDITY IN THE GUARD CELLS

Normal opening and closing of the stomata does not occur except in light, although all other conditions may be made as favorable as possible. Light is the primary cause of opening and closing, but is not the only cause as is shown by the behavior of stomata in light during wilting and the failure of stomata to open on wilted plants in the morning. Light, therefore, can be said to cause a decrease in the acidity of the guard cells and in darkness the acidity increases again. This fact is shown by the colorimetric tests on the guard cells, which show a more alkaline color with Bromphenol blue when opened than when closed, also from the behavior of guard cells in buffer solution of dialysed juice and in alkaline atmospheres. This decrease in acidity as indicated from the behavior of the guard cells in the dialysed juice is most likely from about pH 3.8-3.9, the normal acidity of the leaf juice, to about pH 4.2-4.4 in the morning and reversed in the evening. Whether there is a similar change during wilting can not be determined by these methods. The temporary opening at the beginning of wilting seems to be due to turgor changes of the surrounding leaf tissues. No change in osmotic value or starch to sugar changes were found accompanying this temporary opening, but on permanent wilting the osmotic value and starch content do change considerably.

The results shown in Table 5 on the pH values of the leaf juice indicate that there is no marked change in the acidity of the leaf in light or in darkness as apparently occurs in the guard cells. Acids accumulate at night in certain cacti, but titration tests showed no such change in patience dock. There is some evidence that light may change the acidity of the epidermal cells. When the clear juice from the leaves is titrated

with Na OH a reddish color appears at about pH 5.0-5.2. It is therefore seen that the juice contains a natural indicator.

When leaves which have been growing in reduced light are placed in strong sunlight a reddish color develops in the colorless epidermal cells after a short time. Plants growing out of doors show this reddish color, while those grown in the greenhouse do not. Leaves subjected to alkaline atmosphere show exactly the same red color development in the colorless epidermal cells. These observations would indicate that there is a decrease in acidity of the epidermal cells due to light which does not occur in the rest of the leaf. Similar changes might occur in the guard cells.

There are three theories which could be advanced to account for this decrease in acidity in the guard cells.

a. The decrease may be due to the accumulation of organic acids in darkness which are further oxidized to CO_2 and H_2O in the presence of sunlight. Such changes are known to occur in cacti. This theory would fail to account for the closure of stomata on wilted leaves in sunlight.

b. It may be due to some rearrangement of the components of protoplasm in light where acids are decreased.

c. It may be due to the accumulation of CO_2 from respiration which would be used in photosynthesis in sunlight, but not in darkness. Any cell low in buffer action would be changed considerably by its accumulation.

Micro-chemical tests for minerals in the guard cells showed negative results, but this is not conclusive proof of their absence because of the difficulty of making the test on such small cells. Low mineral content would mean low buffer action. More localized tests might definitely prove this point. The explanation of the behavior in light on permanent wilting could be explained on the theory of low buffer action by dilution or concentration of the H^+ -ions due to loss of water by evaporation.

V SUMMARY

Measurements of the osmotic values of the different cells of the leaf were made by the plasmolytic method and by the depression of the freezing point. The guard cells increase in value in light, but no such variation in the other cells of the leaf were found.

Micro-chemical tests of the starch and sugar content of the guard cells and the starch content of the mesophyll cells were made. The increase in the osmotic value of the guard cells was correlated with a change of the starch to sugar in the guard cells.

The effect of non-toxic buffer solutions adjusted to known pH values was studied. It was found possible to open or close the stomata at any time either in light or in darkness by placing the epidermis in the proper pH value of the buffer solution. A theory is advanced that changes in acidity account for the change of starch to sugar in the guard cells. The probable causes of this change in acidity are considered, but more experimental data are necessary to prove the exact nature of this change.

CONCLUSIONS

The data presented in this paper seem sufficient to warrant the following conclusions concerning the physiology of the stomata of patience dock.

- 1 The stomata of patience dock close completely at night and check the loss of water from the intercellular spaces of the leaf.

- 2 The opening and complete closure of the stomata is the principal cause of the periodicity of transpiration from the leaves.

- 3 When open the stomata modify the rate of water lost from the intercellular spaces of the leaf in proportion to changes in their perimeters, not to changes in their areas.

- 4 Sunlight is the principal environmental factor concerned in the opening and closing of the stomata, while the amount of water in the leaves and the acidity of the guard cells are the two internal conditions directly concerned with stomatal movements.

- 5 The guard cells of patience dock contain green plastids which are structurally, physiologically, and genetically different from the chloroplasts of the mesophyll cells.

- 6 The starch to sugar change in the guard cells is a reversible reaction which goes in either direction, depending on the changes in acidity of the guard cells.

- 7 The series of changes which results in the opening of the stomata is as follows:

- (a) In the morning light decreases the acidity of the guard cells
- (b) This decrease in acidity makes conditions more favorable for the hydrolytic action of diastase
- (c) The diastase in the guard cells changes the starch to sugar
- (d) The formation of sugar results in an increase in the osmotic value of the guard cells
- (e) Water enters the guard cells from the epidermal cells which do not change in osmotic value and causes them to swell
- (f) The swelling of the guard cells causes the pore to open because the thickened cell wall around the pore stretches less than the thinner walls of the cell

8 This series of changes does not take place if the leaves are wilted when light first falls on them. If wilting occurs after the stomata are open the reaction is reversed, so that the sugar changes to starch and the stomata close even in full sunlight

9 In turgid leaves the stomata remain open until evening and then close by a reversal of each change which causes them to open

10 By artificially changing the acidity of the guard cells in non-toxic buffer solutions the stomata can be opened or closed either in light or in darkness

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THE FIRST THREE LARVAL STAGES OF HEXAGENIA BILINEATA SAY

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INTRODUCTION

Although the study of the Ephemeridæ was begun by J Swammerdam in the seventeenth century, our knowledge of the developmental stages through which these insects pass from the time they leave the egg until they appear on land as sub-imagos is still very limited. Quite a number of papers have appeared dealing with the morphology, embryology, taxonomy, biology, and the distribution of Ephemeridæ, but very little has been done towards working out the different stages in their post-embryonic development. The first work of this nature was done by Lubbock (1863-66) on the development of *Chloen dimidiatum*. This was followed by the work of N and E Joly (1878) on *Paligenia virgo* and by that of Vayssiere (1882) on *Heptagenia longicauda*. More recently Murphey ('21) and Gros ('23) have worked out the post-embryonic development of *Baetis posticus* and *Ecdyonurus forcipula* respectively.

THE MATERIAL

The material on which the study of the first three larval stages of *Hexagenia bilineata* has been based was obtained at the Ohio State University Lake Laboratory at Put-in-Bay, Ohio. The larvæ were hatched in the laboratory from eggs that had been fertilized in normal salt solution and then incubated in lake water. The time required for incubation was nine days, this is one day less than the shortest period of incubation that I observed during the summer of '24 in the same laboratory. Clemens ('13) states that the time required for incubation is forty days. The length of time required for hatching varies perhaps with the individual eggs as well as with the temperature. Under identical conditions eggs from the same female fertilized by spermatozoa from the same male differed in the length of time required for incubation.

from ten to twenty-four days. A low temperature would, I think, prolong the period required for incubation, for Murphey ('21) has shown that if in the development of *Baetis posticus* the average monthly temperature is reduced from 62.4° to 45° the length of the aquatic existence is increased by fifty percent.

EGGS

The female deposits on an average about 1500 eggs. Due, perhaps, to the crowded conditions in the abdomen of the female, the eggs are quite variable in shape, some are long ovals, some are elongate with square ends, again others have concave sides, etc. The eggs are whitish in appearance and measure about 27 mm in length and 17 mm in width. The chorion is rather heavy and is surfaced with regular hexagonal figuring. When hatching, the shell splits lengthwise to allow the emergence of the larvæ. The young larvæ become quite active soon after crawling out of the shell.

Because of the transparency of the body-wall, the alimentary canal—filled with yolk globules—can readily be seen. In the head it is a narrow tube, but it widens out abruptly in the prothorax and from there on it gradually decreases in width until the beginning of the hind-gut in the eighth abdominal segment. The beginning of the hind-gut is marked by the origin of the Malpighian tubules and the presence of the pyloric valve. The hind-gut is a short, straight tube. The Malpighian tubules, two in number, extend anteriorly along the ventral abdominal wall until they reach the metathorax, where they are bent dorsally and then extend posteriorly for a distance of several segments.

The dorsal vessel is also seen quite readily and one can see the blood corpuscles enter it and watch their passage from one chamber to the other.

STAGE I

The newly hatched larvæ (Fig 1) measure about 88 mm. in length, not including the antennæ and the caudal filaments. The head is almost quadrangular in shape except that the anterior border is more or less rounded off. From the anterior border of the head between the antennæ arises a small projection, (the clypeo-cephalic prolongement of Lestage). The head is 16 mm wide and 14 mm long. It is almost as wide

as the prothorax and rather wider than the meso- or the metathorax. The head bears five ocelli, an anterior pair, a posterior pair, and one unpaired median ocellus at the base of the clypeocephalic prolongement. All are approximately equal in size and circular in outline.

The antennæ (Fig. 5) 28 mm in length, are composed of five segments of which the first is the shortest and of uniform thickness throughout, the second is rather longer than the first and increases in thickness towards the apex. All the three remaining segments are approximately equal in length and each about twice as long as the second. The second and third segments each bear one bristle near the apex, the fourth and fifth each has a pair of bristles in the same relative position.

The thorax measures 26 mm in length and its three divisions show very plainly. The prothorax is slightly wider, as well as longer than either the meso- or the metathorax.

The abdomen measures 48 mm in length and is composed of ten segments. Each of these is very distinct except the first one, which is so intimately joined to the metathorax that it is rather difficult to make out the presence of ten segments. The segments decrease in width, but increase in length from the first to the tenth. The length of the last four segments is half that of the entire abdomen.

The last abdominal segment bears three caudal filaments, (Fig. 6). Each of these is 32 mm in length and composed of four segments of which the first three are approximately equal in length and the three together are slightly longer than the fourth. The first and second each has a finely toothed ridge near its distal end. The latter also bears one bristle near the apex. The fourth segment tapers down to a point and bears one terminal bristle. In *Ephemera simulans* the last segment bears two terminal bristles.

The fact that the lateral and the median filaments are equally well developed in Stage I distinguishes *Hexagenia bilineata* from several other species that have been described. Lubbock (1866) found that in the first stage of *Chloen dimidiatum* the two lateral filaments were composed of nineteen segments each. The median filament appeared as a minute knob in the second stage and did not show segmentation until the larvæ reached the sixth stage. Vayassiere (1882) found that in *Heptagenia longicauda* the median filament is much shorter than the lateral ones. Gros ('23) found just the opposite

relation in *Ecdyonurus forcipula* Murphey found that in *Baetis posticus* the median filament does not appear until the fifth stage

The three pairs of legs (Fig 4) are all the same and are already well developed, serving as organs of locomotion The coxa and the trochanter are very short and well defined The femur is likewise well developed and its length approaches one-third the length of the entire leg The tibia is almost as long as the femur, and it bears two bristles The tarsus is about half as long as the trochanter and likewise bears one bristle Each leg terminates in a long, heavy claw

The mouth-parts are in the first stage already fairly well developed The labrum (Fig 14) is a simple quadrangular shield bearing on the dorsal side of each anterior angle a well developed bristle The mandibles (Fig 8) show two well developed canines on the outer anterior border and a well marked molar surface on the inner edge The maxilla (Fig 7) bear a number of strong bristles on their free ends and show a slight development of the palpi The labium (Fig 9) as viewed from the ventral side appears like six lobular projections arising from a rectangular base The two lateral lobules, destined to become the labial palpi, are a little longer than the remaining lobules which form the ligula, and each bears two small bristles, one near and one at the distal end

This first stage, which lasts about four days, showed as far as I could discover, no trace of either trachea or gills

STAGE II

Specimens of this stage measure about (length not constant) 96 mm in length The antennæ have increased by the addition of a sixth segment and now measure 30 mm in length The caudal filaments have added one segment and are 36 mm in length The legs bear two additional bristles on the tibia and one on the femur The ocelli show no modifications The front of the head is modified by a decided increase in the clypeo-cephalic prolongement However, the most important change has taken place in the abdomen Along the posterior angles of segments 2 to 7 the gills (Fig 2) have made their first appearance as little evaginations of the body wall Apparently the gills arise from the dorsal part of the segment There seems to be considerable difference of opinion on the origin of

the gills in Ephemeridæ. It has generally been assumed that they are pleural or even ventral in their formation. B. Duerken ('07), however, maintains that they arise from the tergi, while Carl Börner ('09) has claimed that they are modified coxa. On segments eight to nine no gills appear, but a long hair arises in the positions occupied by the gills in the preceding six segments.

The simultaneous appearance of six pairs of rudimentary gills in the second stage is remarkable and it distinguishes *Hexagenia bilineata* from most other species in which the early stages have been studied. Vayssière found that in the first stage of *Heptagenia longicauda* rudiments of gills appeared on segments four and five. In the second stage those of the third and sixth segments appeared well formed, whereas, those of the second segment were rudimentary. Not until the third stage were six pairs of gills visible. In *Ecdyonurus forcipula* Gros ('23) found that gills appeared on segments five and six in the second stage and on four and seven in the fourth stage. It was not until the sixth stage that six pairs of gills were present. In *Chloen dimidiatum* Lubbock found no traces of gills until the third stage, when they were present on segments two to six, those on the third and fourth showing the highest degree of development. Heymons ('96) gives a figure of a young larvæ of *Ephemera vulgata* that shows an equal development of gills on segments two to seven. He does not say what stage it is, but from its appearance and comparing it with my larvæ of *Ephemera simulans*, I conclude that it is not beyond the second stage. Murphey ('21) states that in *Baetis posticus* "gills show as tiny out-pockets of body wall," but does not mention the number.

In my larvæ of *Hexagenia bilineata* of the second stage the gills are all in the same stage of development and there is yet no trace of the seventh pair. No traces of tracheæ are found in either the gills or the body cavity.

The mouth parts of the second stage differ but little from those of the first stage. The canines and molar surfaces of the mandibles (Fig 10) as well as the bristles and the palpi of the maxilla (Fig 11) have increased in size. The labial palpi (Fig 12) are now definitely separated from the ligular portion of the labium and are composed of two or three segments. The hypopharynx (Fig 13) was not studied in the first stage,

although it undoubtedly exists there. It is in this stage composed of one median lobe and two lateral lobes which partially overlap the median lobe.

This second stage, like the first stage, lasts about four days.

STAGE III

The antennæ show no change except a small increase in length. The caudal filaments have added two segments. The legs bear six hairs on the tibia and three on the femur.

There are still only six pairs of gills, but they are much larger (Fig 14) and have become irregular in outline. The division between the gills and the abdominal segments is now much more definite and partakes of the nature of a joint. The gills move freely in an undulating manner.

In this stage the tracheal system makes its first appearance. Two longitudinal trunks, more lateral than median, extend the entire length of the body. Branches extend into the antennæ, towards the eyes, and towards the mouth parts. Branches extend also into the legs and to the muscles of the thorax. In the abdomen, branches segmental in their arrangement, are given off to the abdominal organs of the first eight segments and to the gills on segments two to seven. In the tenth abdominal segment each longitudinal trunk gives off a branch to the corresponding lateral caudal filament. I have been unable to establish definitely the origin of the tracheal branch of the median filament, but, presumably, it is similar to that in the damselfly, i. e., the two longitudinal trunks, after giving off the branches to the lateral filament, join and extend into the median filament.

I was unable to determine the length of the third stage as all my specimens died before the end of it. It lasts, however, at least as long as the previous stages.

In conclusion, I wish to express my gratitude to Professors C. H. Kennedy and Wm. S. Marshall for suggestions and criticisms.

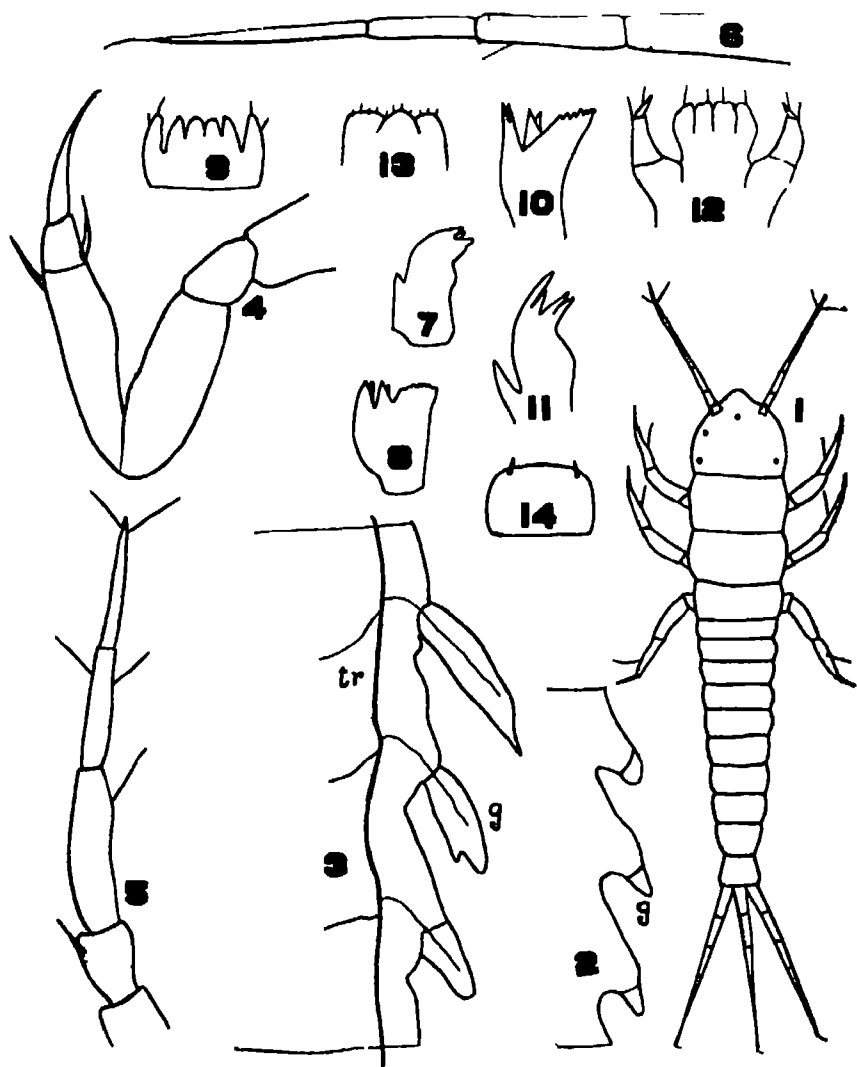
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EXPLANATION OF PLATE

- Fig 1 Larva of the first stage
Fig 2 Right half of abdominal segments 2-4 of the second stage showing beginning of gills
Fig 3 Right half of abdominal segments 2-4 of the third stage showing further development of the gills and the presence of trachea
Fig 4 Dorsal view of a leg of stage 1
Fig 5 Antenna of stage 1
Fig 6 Caudal filament of stage 1
Fig 7 Dorsal view of maxilla stage 1
Fig 8 Dorsal view of mandible stage 1
Fig 9 Ventral view of labium stage 1
Fig 10 Dorsal view of mandible stage 2
Fig 11 Dorsal view of maxilla stage 2
Fig 12 Ventral view of labium stage 2
Fig 13 Hypopharynx stage 2
Fig 14 Dorsal view of labrum stage 2

Note Fig 1 X80 Figs 2-14 X265 Abbreviations g gills tr trachea
lp labial palpi



SIAMESE TWINS OF *ARISAEMA TRIPHYLLUM* OF OPPOSITE SEX EXPERIMENTALLY INDUCED *

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In an article published several years ago, the writer† described a number of dichotomous twins of *Arisaema triphyllum* and *A. dracontium*, all of which showed a very decided similarity of vegetative and reproductive characters and were also exactly alike in sexual expression. Because the reversibility of sex in *Arisaema* had been previously definitely established, the exact correspondence of the sexual nature of these as well as of other identical twins was thus known to give no weight to the often assumed hypothesis that the similarity of sex indicates a differential hereditary basis for maleness and femaleness. The conclusion was thus drawn that "identity of sex in duplicate twins can not be regarded as giving any conclusive evidence in support of the hypothesis that sex is determined by Mendelian factors." The following statement was also made "Although so far the writer has no evidence that *Arisaema* twins placed in different environments would develop the opposite sexual states in a given season, yet, in view of the fact that any ordinary individual can be changed from season to season and that the pairs of twins have actually reversed their sex to the opposite state in agreement with a change in nutritive environment, it appears that such must be the case."

In the meantime Maekawa‡ has shown that the sexual condition of *Arisaema japonica* is essentially the same as in *A. triphyllum* and can be controlled by experimental means.

A small carpellate plant, transplanted to the garden, developed a dichotomous cleavage of the bud and thus became the subject of the experiments described below. This carpellate plant, along with others, was taken from the forest in 1922 and placed in an experimental plot. In transplanting, both the roots and leaves were injured to such an extent that in 1923 it

*Papers from the Department of Botany, The Ohio State University No 166.

†SCHAFFNER, JOHN H. The Sexual Nature of Vegetative or Dichotomous Twins of *Arisaema*. Ohio Jour Sci 22 149-154. 1922

‡MAEKAWA, TOKUJIRO. On the Phenomena of Sex Transition in *Arisaema japonica* Bl Jour Coll Agr Hokkaido Imp Univ 13 217-306. 1924.

produced only a vegetative shoot. But it now showed definite signs of twinning, having two similar leaves distinct from the very base. The leaf surface was somewhat reduced by cutting off the tips and the plant was kept in comparatively dry condition during the spring growing season.

In 1924, according to expectation, definite twin shoots were produced and both were pure staminate, according to the treatment given for the control of the sexual state. The two shoots were still united for the most part by the original corm. These identical twins were absolutely alike in size and vegetative and reproductive characters. The anthers were a conspicuous red. From appearances, it seemed probable that these Siamese twins would be united for another season, so a careful attempt was made so to control the food supply of the two growing buds that one would change to female while the other remained in the male state. The leaf surface of the one now staminate twin was much reduced while its brother was left intact with a normal leaf development. The twins were then treated with an abundance of water for some time, and carefully watched and cultivated so that differential physiological gradients might be established in the two forks of the corm and differential growth and food storage take place. Of course, it was not possible to apply any accurate quantitative treatment, since food could easily be transferred from one side to the other. It was merely a matter of judgment as to what should be done, gained from former experience in controlling the sex of *Arisaema*. The attempt was to develop just the proper balance that the one bud would just reach the condition to induce female determination and still keep the other one reduced sufficiently to continue it in the male state. It was, of course, recognized that too great a deprivation of food of the proper sort would cause a sterile shoot without inflorescence to develop.

In the spring of 1925, the results of the experiment were awaited with anxious anticipations of success or failure. For as intimated above, it was well known that success would depend on a very close margin in the control of the storage and transference of food in the two buds of the still united corm. But when the two "jacks" began to break out of their "pulpits," all proved to have been done properly. For the "Siamese twins" were one staminate and the other carpellate—male and female. The one treated for staminateness was staminate and the one treated for carpellateness was carpellate. The attempted

balance had been properly accomplished. The female condition was just intense enough to hold out to nearly the end of flower development on the carpellate spadix, maleness being only very slightly expressed at the very last stage. There were a small staminate flower and a vestigial flower at the top of the inflorescence. The staminate plant was pure in sexual expression and also according to expectation, was noticeably smaller in size than the carpellate twin. See the accompanying Figure 1. The staminate plant had the same characteristics as the



FIGURE 1

Siamese twins of *Arisæma triphyllum*, one male, the other female. Note the difference in size between the staminate and carpellate plants. The spathes have been folded back so as to expose the spadixes.

staminate shoots of the previous season, with bright red anthers. The stigmas of the carpellate flowers were green, while the anthers of the small staminate flower, according to genetic expectation were typically red. Outside of the difference in size of the two plants there was also some difference in the robustness of the peduncles, that of the carpellate plant being the larger. The vegetative hereditary characters were exactly alike and the "jacks" or sterile tips of the spadixes were both

green as they had uniformly been at all previous developments. The sexual dimorphism of the two spadixes, however, appeared quite prominent because of the decided difference in color between the anthers and stigmas.

The twins were now dug up and examined carefully and were found still to have a considerable connecting bridge of living tissue between the two forks of the corm. Here then we have a case of plant Siamese twins, originally of the same sex, in which opposite sexual states were induced by a carefully estimated control of the food supply produced in the leaves together with a proper water and nutrient supply from the roots.

As stated in the previous paper and confirmed by further observations, the dichotomous twins of *Arisaema* are normally of the same type of sexual expression, whether staminate, carpellate, or some degree of monociousness. It is only rarely that one finds twins, both those still united and those already separated but still growing side by side in the same intimate environment, that show some very slight difference in sexual development. Occasionally one can find carpellate twins for example in which one individual is pure carpellate and the other carpellate with one or two imperfect or perfect staminate flowers at the tip of the spadix.

It is established then, that sameness of sex in identical twins cannot be used as evidence for the hypothesis that sex is determined by heredity, nor for the supposition that identical twins have the same sex because they have the same heredity. Such a conclusion is unwarranted in any event, without additional support, because correspondence of phenomena does not establish a causal relation.

As is well known, in the nine-banded armadillo* nearly every female gives birth to quadruplets and all in a given set of quadruplets are of the same sex, either four females or four males. This indicates as in the case with identical twins of other higher animals that sex is determined in the egg before any cleavage takes place. Differentiation processes are set up which establish the given sexual state so that no reversal under ordinary conditions takes place. And this may be further intensified by the differential presence of allosomes having a pronounced effect on the established physiological

*See "The Physiology of Twinning," p 100 H. H. NEWMAN The University of Chicago Press 1923

gradients The continuity of the sexual states in the twinning process is, however, not different than its continuity in plants derived from cuttings in numerous higher species Sexual conditions can become highly fixed through differentiation as well as can vegetative conditions The primary cause of sex determination which starts a definite course of differentiation in the normal environment is undoubtedly the same in animals and plants, whether they have allosomes or not, since it is now known that both plants and animals with allosomes show sex reversal the same as those without such specialized chromosomes. There can be no question but that the sex of incipient twins, which have not passed through a differentiation cycle, is subject to reversal even more readily than that of mature or differentiated individuals In the latter, dedifferentiation has been accomplished and the sex reversed in both plants and animals, by a proper manipulation of either the external or internal environment

In conclusion, then, it can be stated that the sex of identical *Arisaema triphyllum* twins is normally the same, but that this does not at all imply that the sameness is due to a differential hereditary cause, since it is demonstrated that by a suitable manipulation of the environment, these identical twins, even after they have been developed as blooming plants and even while they are still connected by a considerable band of living tissue, can nevertheless be developed so as to be, simultaneously, the one a male and the other a female

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THE SOCIAL SIGNIFICANCE OF SCIENCE *

PAUL M REA

BEGINNINGS OF SCIENCE

Insatiable curiosity is one of the most important characteristics of the human mind. From his earliest days to the present, man has observed and wondered and been ill at ease until he has found satisfactory explanations of natural phenomena. Every primitive people has these explanations. However fantastic they may seem to us they are nevertheless just as reasonable as our own when consideration is given to the limited experience and knowledge on which they are based.

These primitive explanations of natural phenomena are so soon formulated that they begin to be modified by further experience. Here are the beginnings of philosophical and religious speculation and of science. Religious speculation is primarily concerned with the unknown, philosophical speculation with the projection of the known into the unknown, and science with the known. The early progress of science is excessively slow. The power of tradition is great and old beliefs give way but slowly to new ideas. Step by step however, naturalistic ideas make inroads upon the field of pure imagination. There is never-ceasing conflict between tradition and new knowledge.

The field of the known is ever increasing, but the unknown ever extends limitless beyond. Some minds find satisfaction in the known. Some are chiefly concerned with the unknown but apparently knowable borderland. Some find compelling fascination in the further distances of the unknown where imagination can have free play.

* Presidential address at the Thirty sixth Annual Meeting of the Ohio Academy of Science held at Columbus, Ohio, April 9 and 10 1926

THE PRICE OF SPECIALIZATION

These three interests have been characteristic of all ages. The great change that has taken place is the stupendous increase in the scope and complexity of knowledge. This has had two momentous consequences. The first of these is that no thoughtful person can now orient himself toward life and environment without a broad understanding of science. The second is the increasing difficulty of acquiring such an understanding. The time when an alert mind could fairly comprehend the sum of knowledge is not far behind us, but it is gone beyond recall. The problem before us is to find means of maintaining a broad culture in the midst of ever-increasing specialization upon ever-decreasing segments of knowledge. The solution of these problems requires an interest in imparting knowledge among those who know and an interest in receiving knowledge among those who do not know. Most of us are among those who know in some small field and among those who do not know in many other fields. However dangerous a little knowledge may be, one of the real needs of modern society and one destined steadily to increase, is for accurate general information. The urgency of this need in respect to the field of science can be appreciated only after some consideration of the influence of science upon modern society.

THE YOUTH OF MODERN SCIENCE

Our own civilization and social structure is of recent origin. Its immediate beginnings are to be found in what we call the Renaissance. This was a profound but gradual change resulting from the freer circulation of men and thoughts associated with the Crusades, with the widening of the horizon by travelers like Columbus, with the invention of printing, the re-discovery of Greek culture, the development of universities and learned societies, the establishment of museums and botanical gardens. It was a period of revival of interest in learning, and it was beginning to bear complex fruits in the Sixteenth Century.

Our culture is thus built in part upon the culture of classic Greece, in part upon the learning of our own period. Slowly during the early part of this modern period scientific methods were perfected and fundamental concepts of science established. With these foundations laid, an ever-increasing acceleration of scientific progress has ensued.

OUR SCIENTIFIC AGE

One of the results of modern science has been the growth of our present civilization upon a foundation of applied science. The life of the people is conditioned largely by the utilization of natural materials and forces made possible by science. The mechanisms of applied science and the industrial processes by which they are produced have a major influence in determining the environment, the occupations, and the habits of thought and behavior of mankind. Science makes the preparations for our reception into the world, prescribes the diet, clothing, and daily routine of the infant, provides the houses in which we live, together with our food, fuel, water, light, furnishings, and multiple labor-saving mechanisms. Science determines the occupations of most of us, and where and under what conditions our working life shall be spent. Science provides the means of transportation and thus controls the range of our movements, a large part of our play, and the breadth and nature of much of our thinking. We depend upon science to keep us well, and we turn to science when we are ill. It is no wonder we boast that we live in an age of science!

EFFECTS OF SCIENCE

These profound changes in human life are the results of applied science. They are of such recent development and of such obvious portent for good and evil that they require the most serious consideration of mankind. In so far as they facilitate the meeting of the primary necessities of life, conserve health, broaden the horizon of our experience, and increase leisure, they ameliorate the harshness of a more primitive manner of life and open possibilities for the enrichment of life. Whether at the same time they soften the fiber of the people and sow the seeds of decay in the civilization of which they are the outstanding characteristic, is uncertain. We know, although we may not always remember, that throughout the long history of life every great expansion has been followed by a decline to extinction or obscurity. Every human civilization has flowered only to decay. In no nation and at no time in history has prosperity been so nearly universal as it is with us today. By all standards of the past we are now arriving at a pinnacle never surpassed. In the very greatness of our achievement we cannot but sense a note of warning. If our material

prosperity leads to habits of luxury and indulgence, to indifference to the fundamental problems of individual life and of society, our prosperity may well become a curse. If, on the other hand, our increasing knowledge and leisure lead to the enrichment of our individual inner lives, to a greater interest in a more intelligent approach to the multitude of unsolved problems of society, we may well hope to continue our progress in the building of a finer social structure and a greater personal happiness than any people has yet attained.

It is not conceivable that the progress of science will soon be retarded. We must rather expect an ever-increasing acceleration and an ever-increasing complexity of life resulting from this acceleration. Our main reliance must be placed upon more science, not merely in the production of more mechanisms, but especially in those fields of science which hold promise as yet but dimly apprehended of a truer knowledge of the reactions of men to their physical environment and to their social contacts with one another. The increase of happiness in the broadest and highest sense of the word, happiness not of a favored few but of all, is a worthy object of human endeavor.

THE SPIRIT OF SCIENCE

Applied science is undoubtedly highly appreciated by mankind, but the spirit of science is far from being generally appreciated. The great contribution of science to humanity lies in its indefatigable industry in accumulating facts, in its honesty in facing whatever facts are found and whatever principles those facts may indicate, and in its open-minded readiness to modify its opinions in the light of new evidence. We cannot have true science without sincerity in the search for truth and without the realization that most truth is relative. The attitude of science stands in sharp contrast to the attitude of the unscientific, which is controlled by tradition and by emotion. Prejudice and lack of understanding of science, especially biological science, is one of the handicaps in the intellectual adjustments of the people to the progress of knowledge and in social practice and legislation.

The mechanistic products of science are quickly accepted by the people. So largely do these utilitarian results bulk in the popular mind that they are all too commonly regarded as the sole purpose of science. "Of what use is it?" is the first question of such minds regarding knowledge. It is of the greatest

importance that the general public learn to appreciate, first, that useful inventions are invariably developed from apparently useless knowledge—there can be no applied science until we have science to apply—and, second, that the mechanisms of civilization are but the paraphernalia of life, that the most precious human experience, the highest form of happiness, lies in harmonizing the experiences of life and in adjusting ourselves satisfactorily to life and to our environment. This orientation of one's self in life has been from time immemorial the great desire of human beings. Science is rapidly providing a necessary basis for this orientation. Never before in all the long millions of years of the history of life, we may be sure, has any species ever before attained an objective point of view toward itself, projected its mind into the magnificent distances and dimensions of astronomy, into the remote time of geological history, into the minute realms of chromosomes, bacteria, atoms, and electrons.

Even today we are just beginning to apprehend what natural history means, beginning as it does in infinitely remote time and space, sweeping like a great stream through the ages, seeming to pause a moment in the eddy of our personal experiences, and sweeping again in full flood toward an infinitely remote future. Only with some understanding of these major concepts of science can we hope to experience the full richness of modern life, or to make such adjustments in our attitude toward life as are worthy of the minds with which we are endowed, and of the rich race experience that is our heritage.

THE SOCIAL DUTY OF SCIENTISTS

It takes many men of many kinds to make a world. Scientists tend to withdraw themselves from the turmoil of practical life, to associate with kindred minds, and to seek the seclusion of the laboratory and the study. This is appropriate in so far as it facilitates that concentration which is essential to research, yet it is but the first step in meeting the social need of science. Some fortunate scientists are able to emerge from the cloister either in person or through the written word with a message of great import to humanity. These perform a social service of the highest order. I conceive one of the great needs of society today to be the provision of more effective means for the interpretation of science to the general public.

The progress of science is recorded by custom in technical publications. These are a necessary and admirable means of communication between scientists of the present and of the future. It must not, however, be forgotten that these technical publications are written in a dialect incomprehensible to the people, and that the ultimate end of research is to contribute to society. Society needs accurate and judicious interpretation of science.

SCIENCE IN EDUCATION

One of our most characteristic institutions for the interpretation of knowledge is our educational system. Since we are living beings in a world of nature, it would seem that no college course would be complete without a serious presentation of what is known about life and its environment. In actual practice, however, science occupies a much more subordinate position than would seem natural from our present point of view. I attribute this to two general causes. First, failure of the general public to appreciate the magnitude of the concepts science has to offer. Second, the failure of science faculties to appreciate how much more important the major concepts of the sciences are in education than the minutiae.

I well remember how in my college days I was thoroughly imbued with the idea that science is a very serious matter, that I must train my powers of observation by prolonged search for minute facts with the careful recording of my observations in notes and drawings, and that only by long practice in small generalizations might I come in time to understand the spirit and the broader conclusions of science. Looking back I find no fault with this experience as a foundation for science as a profession. I am impressed, however, by the very small proportion of college students who go far enough with such a program to obtain the kind of understanding of science that ought to be a part of the equipment of every college graduate.

Even in the most intellectual circles of a great city I hear little discussion of most of the subject matter of my college courses in science. Principles of erosion, Boyle's law, chemical formulae, Amoeba, the anatomy of the earthworm, alternation of generations, the germ layers, are not subjects of general conversation. I do hear, however, at the round tables in the clubs, at social dinners, in short wherever intelligent men and women gather together, expressions of vivid interest in scientific

events and discoveries I take as my type of the better element of the general public the successful business man and his family. They are endowed with good minds, they are well educated, they are deeply immersed in the problems of their vocation, they are of an inquiring disposition, they want to know what is happening in the world and what it signifies, they desire culture but find it rather difficult to attain. They are interested in events and the significance of events. Their interest does not begin with general principles and proceed to the illustrations. It begins rather with particular events and is not satisfied until the principles that give them significance are indicated.

My experience suggests that a sharp distinction should be made in the college curriculum between courses of professional training and courses of general culture. However assured we may be that one cannot fully comprehend a scientific problem except by studying all its details, we must admit that one may at least apprehend a principle from consideration of conspicuous illustrations.

The successful college course must meet two fundamental conditions. It must present accurately and in due proportion the important concepts of the subject. It must also make the largest possible contribution to the enrichment of the mind of the student. The student's needs may best be understood if we consider what influence the subject matter of the course may be expected to have upon his later life. The success of the course will be proportionate to the degree to which it illuminates his experiences.

One of the best popular lecturers on astronomy that I know is a lawyer to whom astronomy is a recreation. Popular audiences are fascinated by his astronomical descriptions. Their effect is to broaden the mental horizon of the hearers, and to give significant facts that may serve as the nuclei around which may adhere ideas obtained from other sources.

In practical life most people are not interested in mathematical physics or in chemical formulae, but they are greatly interested in the nature of matter and the inter-relations of its various forms as seen by the physicist and the chemist. In geology they are not interested in the intricacies of crystallography, but they are greatly interested in the history and structure of the world in which they live. In biology they are not interested in the anatomy of animals that are for the most part outside their experience, but they are deeply interested in

the living things about them, or which come into their experience through the work of expeditions. Whenever their attention is drawn to facts, their minds are receptive to an explanation of the significance of the facts.

NATURAL HISTORY

A hundred years ago natural history was a term in general use to cover the field now apportioned among the sciences of astronomy, geology, paleontology, biology, and anthropology. The increasing complexity of these sciences has obscured the fact that they are but different aspects of one great unit—nature. There is already noticeable in college curricula a tendency to overstep these departmental fences and to offer courses of increasingly broad scope. This is the logical step toward meeting the needs of students who take science for general culture. General science is a rather heavy and uninspiring title. The good old term, natural history, is coming back into use. I commend it to the consideration of the colleges for the richness of its connotation and the directness with which it describes the kind of science for which I find so great a need in society.

THE SOCIAL NEED OF SCIENCE

At best a college education opens the doors ajar to a series of fascinating vistas of human thought and experience. Among these a student can hardly select more than one for intensive exploration in later years. There is an inevitable tendency for the other doors to swing to and leave the vistas to which they lead as mere memories. There is increasing consciousness of a real social need for means of maintaining the vividness and extending the richness of college experience. There is also an increasing consciousness of the social need of better methods of interpreting knowledge to those who have not had college experience. These needs are evidenced by the space devoted to science in newspapers, magazines, and books, by the popularity of lectures, and by the conversations of social groups.

MUSEUMS AS INTERPRETERS OF SCIENCE

As agencies of public education, museums are coming to perform an increasingly important social function. In this country the museum movement is older than the nation. It began with the founding of the Charleston Museum in Charles-

ton, South Carolina, in 1773 This founding, curiously enough, was an expression of a part of the Revolutionary spirit The committee which founded this institution included Charles Cotesworth Pinkney, and its minutes state that it was animated by a desire to show the intellectual independence of the Province of South Carolina from the mother country

In more than 150 years since the initiation of the museum movement in America, there have naturally been many phases of museum development Between 1814 and 1826 there was in Charleston an intensity of public interest in museums astonishing to contemplate "The State Legislature and the City Council, alive to the importance of this object, with a promptness and liberality, which will forever redound to their credit," made the first appropriations of public funds for museum purposes on record in this country, and these appropriations, together with sums subscribed by individuals, were applied to the purchase of an extensive natural history collection brought to Charleston by Dr Felix L'Hermier South Carolinians in the diplomatic service procured extensive foreign collections for the enrichment of the museum, among these was the Hon Joel R Poinsett, minister to Mexico, from whom the Poinsettia is named The collections were described as rich in minerals, fossils, and shells, in ornithology, herpetology, ichthyology, and entomology There were 800 mounted birds, 70 mammals, 200 fishes, and 4,000 minerals The exhibits were arranged in glass cases, and the museum was advertised as "open every day from nine o'clock, and brilliantly illuminated every evening" An editorial in the *Courier* of November 23, 1824, contains this remarkable statement "In these enlightened times, a public museum is as necessary an appendage to a city, as a public newspaper or a public library "

This extraordinary activity of a museum as a public institution was not without parallel in other cities, notably Philadelphia and Salem, Mass Museums of this type were usually founded by societies

Early in the Nineteenth Century two other classes of museums were conspicuous One is that of the scientific societies, among which are conspicuous the Academy of Natural Sciences of Philadelphia, founded in 1812, and the Boston Society of Natural History, founded in 1830 These museums were primarily of the research type The scientific publications based upon them mark milestones in the progress of American

science, but these museums have not been adapted to the performance of the functions of public museums as we now conceive them

The second class of museums conspicuous in the first half of the Nineteenth Century was the college museum. Most of the colleges of the period were denominational colleges. Nearly all of them maintained chairs of natural theology. The principal thesis of these chairs was the evidence of the nature of deity as shown in the complexities and adaptations of creation. The museum of natural history was the laboratory of the chair of natural theology. It had a profound influence upon the college graduates of the period, and as they traveled to the far corners of the earth they sent back to the college museum new examples of the wonders of creation. Museums in this period were a vital part of our colleges.

The publication of Darwin's *Origin of Species* in the middle of the century inaugurated a profound change in the attitude toward nature. The main thesis of the chairs of natural theology was undermined. Interest in the museums declined. A new interest arose in laboratory studies of morphology and embryology. Selected forms in quantity for dissection, and small synoptic series for demonstration replaced the museums. Departments of biology were everywhere established, usually by robbing the museums of their curators.

Approximately 38 percent of the 600 museums nominally existing in the United States belong to schools, colleges, or universities. Most of these museums have no vital college function, and a great majority are practically without funds inactive and deteriorating.

The greatest and most active museums of America today, with few exceptions, are of a new type which may be designated, for want of a better term, as public museums. Some of the greatest of these were founded in the last quarter of the nineteenth century, including the American Museum of Natural History, 1869, the New York State Museum, 1870, the Milwaukee Public Museum, 1882, the Brooklyn Institute of Arts and Sciences, 1889, the Carnegie Institute Museums, 1896. Public museums have two outstanding purposes. Research for the increase of knowledge, and the interpretation of science to the people for the enrichment of life. These museums are usually supported by a combination of private and public funds. Their importance to society increases with the urban

concentration of population. They stimulate and guide interest in local natural history and they bring the natural history of the far corners of the earth into the city for educational purposes. More and more these public museums are becoming the centers of the science interests of their communities.

THE SCOPE OF MUSEUMS

In contrast to the university, the museum deals potentially with the whole public almost literally from the cradle to the grave, while the university deals with but a limited fraction of the public enrolled from four to eight years. Where the university's instruction is intensive, that of the museum is extensive. The university represents a concentrated molding and directing influence upon the early years of adult life, the museum combines instruction with recreation, and stimulates rather than compels attention. Public museums work in close partnership with the public schools, where they have an important and unique social service to render.

MUSEUMS IN ADULT EDUCATION

In adult education these museums have an equally important service to perform. They offer one of the most promising means of continuing and developing through adult life the interest in science that is created in college, and to the non-college public they afford a substitute for college training in science. Up to this time adult education in museums has been chiefly through the arrangement and labeling of exhibits, and through lectures given in the museum or before other organizations.

The great reserves of material necessary for the technical work of museums have not hitherto been effectively utilized for any form of adult education. There appears to be here a fertile field for development. Experiments on a small scale indicate that it is quite possible to bring small classes of adults into reserve collections, and that the offer of this service will be eagerly accepted by the public. These groups should be given organized instruction quite different from that of regular or extension university courses. Appointments of an hour and a half each, once a week for four weeks, offer sufficient opportunity for a cultural experience of distinct social value. Such brief courses can be taken without too great disorganization of the complex activities of adults. The most accessible

clientele for such cultural courses will probably be found among intelligent women who can take these courses during the day. In order to reach men it will be necessary for the museums to provide evening instruction.

Among public museums we can already find some of the most fundamental thinking and skilful methods for bringing about a sympathetic understanding between technical scientists and the general public. These museums offer fascinating possibilities as the intermediate wheel to gear together the power wheel of research and the work wheel of practical life. The educational work of museums is not a duplication of school or college work, but a parallel service, and there should be close understanding, sympathy, and co-operation among these institutions. The educational departments of museums will furnish the technique of interpretation, their scientific departments will furnish the facts and principles. College scientists can make important contributions to this service and in doing so can receive valuable suggestions and stimulation.

If there is such a need as I have described for the interpretation of science to the people, and if there is need for co-operation among colleges, museums, and scientific institutions generally in this social service, the Ohio Academy of Science should have a function of significance to the whole State.

OPPORTUNITIES OF THE OHIO ACADEMY OF SCIENCE

The Academy is the common meeting ground of the scientific activities of the State. One of its important functions is to provide a forum for personal contact and exchange of ideas that cement together in friendly association the scientific men of the State. This function is so obvious and so generally appreciated that it does not need to be stressed.

The second function of the Academy requires more thought. This is the interchange of institutional and personal programs in order that each of us may be better informed about the scientific work in progress in the State, and in order that we may co-operate more effectively in a common cause. I recommend that consideration be given to the desirability of conferences for the specific purpose of articulating more closely the varied activities in Ohio.

The third function which seems to me to devolve upon the Academy is that of presenting to the people of the State by means of special papers at the Academy meetings, and with the

organized aid of the newspapers of the State, broad summaries of the progress of science in the State. There are two important reasons for doing this. The first is the obvious duty of scientists to contribute as largely as possible to the enrichment of the life of the people. The second is that the progress of science depends upon the financial support and social encouragement which it receives, and these can come only from a general appreciation on the part of the people of the importance of science and very clear understanding of the needs of scientific workers.

The Ohio Academy of Science has a long and honorable history. It is so constituted as to possess inherently a large potential influence. Its very nature imposes upon it a serious obligation to serve society to the best of its ability. The more intimately we integrate ourselves with the general public, the greater will be the mutual advantages to be experienced.

Science is one of the dominant factors of our age. Its complexities are bewildering. Its spirit and its meaning are but dimly apprehended by society. My plea is for the enhancement of the social value of science in the enrichment of the life of the people, in the adjustment of personal experience to the world of phenomena, and in the diffusion of the scientific spirit of indefatigable industry in accumulating facts, of honesty in facing whatever facts are found and whatever principles those facts may indicate, and of open-minded readiness to modify opinions in the light of new evidence.

PRINCIPLES OF PLANT TAXONOMY III *

JOHN H. SCHAFFNER

Important evidences of relationships are obtained from a study of the life cycles of plants. A knowledge of life cycles is of special importance in delimiting classes and the higher subkingdoms. In fact, the whole phyletic scheme of relationships depends to a very decided extent on the theoretical views that are held as to the origin and evolution of the numerous types of life cycles present in the plant kingdom. In general, all types of life cycles fall into two divisions, the non-sexual and the sexual.

NONSEXUAL LIFE CYCLES

In the lowest forms of unicellular plants the cycle is simply 1 Increase in size of cell, 2 division of cell, 3 separation of daughter cells. These three primary processes are a part of all normal life cycles, whether sexual or nonsexual, from the lowest to the highest.

The first modification of this primitive cycle is a delay in the separation of the cells after division, giving rise to all sorts of colonial forms—linear, superficial, and solid aggregates of similar or undifferentiated cells. The cycle is then 1 Increase in size, 2 division, 3 delayed separation (an intimate association of cells for a greater or less length of time), 4 separation.

The third type of nonsexual cycle is present in nonsexual, differentiated plants in which, during the period of association after division, the cells are differentiated from each other, giving rise to differentiated, multicellular individuals. Among the blue-green algae, *Rivularia* represents such a plant with a considerable diversity of cells. The life cycle then becomes 1 Increase in size of cells, 2 division, 3 indefinite association or hanging together of cells, 4 differentiation of cells, 5, separation of reproductive cells. These three types of cycles are also parts of the cycles of sexual plants which add two very profound stages—the fusion of gametes and the reduction division.

* Papers from the Department of Botany, The Ohio State University No. 175

In the slime bacteria (*Myxobacterales*) the life cycle is characterized by the association of the cell units for a long time in a pseudoplasmodium. The cells are, however, not intimately connected as in a colony or multicellular individual and at the end of the life cycle the entire mass of bacteria in the pseudoplasmodium usually builds up a complicated elevated structure or cyst which externally resembles the fructifications of slime molds and of the higher fungi.

LIFE CYCLES OF SEXUAL PLANTS

THE NEMATOPHYTA

The development of sex in the organic kingdom represents one of the most remarkable or perhaps it might properly be said the most remarkable event in the whole history of evolution. At a certain stage or period, cells develop primary sexual states and react toward each other in such a way that they are attracted and fuse. We say the one is in the female state or (+) and the other in the male state or (—). This union of cells is just as remarkable, and so far an unexplainable process, as that other more primitive process, cell division. The lowest gametes are isogamous and these lead up to the higher, heterogamous condition. The union of the gametes and their nuclei, however, does not involve the union of the chromosomes, which remain as distinct individualities and are thus doubled in the zygote. Fertilization which properly means conjugation, therefore, requires an "undoing" process or segregation process to separate the chromosomes into two complements with the original numbers. The reduction division is a necessary complement of fertilization. At reduction, the individual pairs of chromosomes or synaptic mates are sexualized and conjugate in the nucleus and are then segregated by the law of chance into the two resulting daughter nuclei. Conjugation or fertilization takes place between the sex cells which are normally haploid and have the primary sexual states. The reduction division normally takes place, in the various groups of plants, at three definite points giving rise to three general types of life cycles, the simple haploid sexual cycle, the simple diploid sexual cycle, and the alternation of generations cycle. In the diagram below, the main types of life cycles and some of their modifications are represented.

The life cycle of the unicellular sexual plants, to whatever group they may belong, is a modification of the unicellular nonsexual cycle thru the development of sexual states at certain periods. *Sphaerella* is a typical example. Single haploid cell, increase in size, division, isogametes, discharge of gametes, conjugation, resting diploid zygote, germination of zygote with a reduction division giving rise to four reduction spores, development of the spore to a normal unicellular individual.

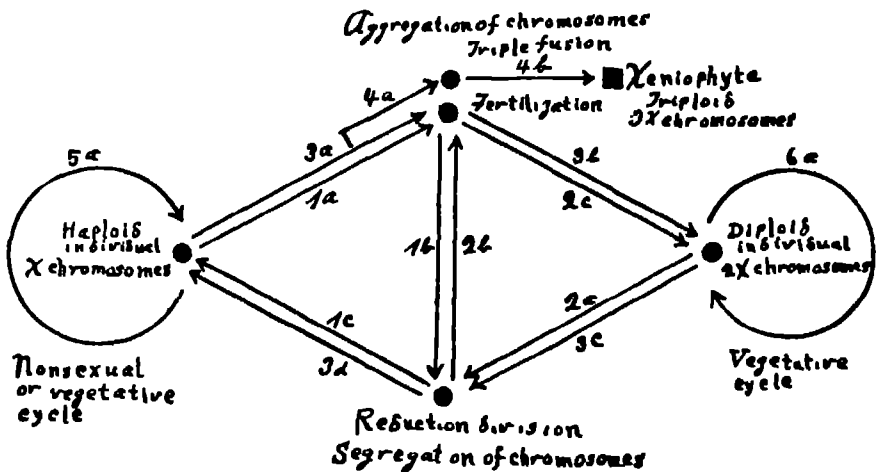


Fig 1 Life cycles of organisms, generalized diagram From the winter's "Laboratory Outlines for General Botany" Fifth Edition

- 1 Simple sexual cycle, the individual being haploid Haploid gametophyte—fertilization—reduction (1a-1b-1c)
- 2 Simple sexual cycle, the individual being diploid Diploid gametophyte—reduction—fertilization (2a-2b-2c)
- 3 Life cycle with antithetic alternation of generations Haploid gametophyte—fertilization—diploid sporophyte—reduction (3a-3b-3c-3d)
- 4 Life cycle with antithetic alternation of generations and xenophyte Haploid gametophyte—fertilization and triple fusion—diploid sporophyte and triploid xenophyte—reduction (3a and 4a—3b and 4b—3c-3d)
- 5 Haploid vegetative and non-sexual spore propagation (5a) This cycle also represents the primitive nonsexual cycle
- 6 Diploid vegetative and nonsexual spore propagation (6a)

which may divide vegetatively for some time (See Fig 1 1a - 1b - 1c) In the colonial forms and those with differentiated multicellular body, the life cycle is the same except that in the vegetative period the cells hold together

All three types of general life cycles found in the Nemato-phyta probably originated directly from the unicellular condi-

tion and consisted of a two-phased condition represented by a haploid and a diploid cell as in *Spharella*. In the higher development of the simple, haploid sexual cycle, the main evolution was in the multicellular development of the vegetative, neutral phase. In *Coleochaete* there was an addition of vegetative divisions before spore-formation following the reduction division in the zygote. This multiplication of divisions after reduction is known in other plants and in certain animals. It does not represent a true alternation of generations. In *Coleochaete* the individual is haploid, in *Fucus* it is diploid. In both cases the multiplication of cells after the meiotic phase is to be regarded as a vegetative intercalation.

If a vegetative multicellular phase is developed between fertilization and reduction, a simple, diploid, sexual cycle becomes established as in animals, Charophyta, and Fucaceae.

If the original haploid unicellular plant evolves a multicellular haploid body and at the same time intercalates a vegetative phase between fertilization and reduction thru a delay in the time of sexualization of the synaptic mats and if this intercalated phase results in a diploid multicellular body, the result will be an antithetic alternation of generations. This life cycle is present in some of the red and brown algae and especially in the typical antithetic cycle of all the meta-thallophyta. The term alternation of generations is often used in a very loose way to designate life cycles of very diverse types. Animals, Rockweeds, and Spirogyras, for example, do not have an alternation of generations. With the evolution of the sexual state the life cycle established depends then on the stage at which sexualization of cells (gametes) takes place, the time at which sexualization of the synaptic chromosomes (reduction) takes place, and the point or points of the life cycle at which vegetative growth and differentiation take place. As stated above, there are three primary types each with its particular stage at which reduction takes place. The three sexual cycles can then be modified in various ways by changes or modifications of the time of sex determination, loss or partial loss of primary sexual states at given points in the cycle and intercalations of vegetative divisions at various points.

MYXOMYCETAE The Myxomycetes must be regarded as plants which were highly differentiated in certain functional processes while still in a rather primitive morphological condition. Their nuclei are well organized. They are not to be

regarded, as has commonly been the case, as primitive plants. They are on a much higher level than the Schizophyta. The life cycle in the typical forms seems to be as follows: Vegetative haploid plasmodium, beginning of sporangium stage with conjugation of pairs of nuclei, later stage of sporangium with diploid nuclei, reduction division resulting in the production of the nonsexual haploid resting spores, liberation of zoospores from the resting spores, amoeboid protoplasts, coalescence of amoeboid protoplasts to form the plasmodium.

ZYGOPHYTA In the conjugates like *Spirogyra* there is a simple haploid sexual cycle. Nonsexual or reduction cell, development (germination proper) of the haploid gametophyte, gametes developed with slight modification inside of the cells, fertilization thru conjugation tube, diploid zygospore, resting condition, reduction division in the zygote during germination, survival of one of the four reduction nuclei in the zygospore wall which becomes the initial cell of the new generation. There is no alternation of generations and no evidence that the group ever possessed such a condition.

GNIDIOPHYTA So far as known all the typical green algae have haploid individuals, except apparently some of the Siphonaeae, the reduction division taking place in the zygote. In *Codium tomentosum*, May M. Williams found that the cenocytic body contained nuclei having the diploid number of chromosomes ($2x$) and that reduction takes place before the formation of the gametes. Hence the life cycle is essentially like that of *Chara* or *Fucus*. Whether the Siphonaeae have this type of life cycle in general is not known. The question arises whether the time of reduction may be shifted in the life cycle of lower plants from one point to the other as the time of sex determination is shifted in the higher plants.

Since reduction normally requires two divisions resulting in four cells for its completion, the normal condition is the development of four spores or four gametes. These four cells are not to be regarded as a generation of an alternating cycle, if our terms are to mean anything in particular. If further vegetative divisions occur they are to be regarded as vegetative intercalations. If the process is leading up to nonsexual spore formation, the mass of resulting cells may for convenience be called a haploid sporophyte, as in *Coleochaete*, but is never to be homologized phylogenetically with such diploid sporophytes as *Riccia*, which has been done quite generally in the past.

Ulothrix may be taken as a normal representative of the *Gonodiophyta*. Its life cycle is Haploid gametophyte, isogametes, conjugation in the water, zygote, resting stage, reduction (?), reduction zoospores, germination.

The *Oedogoniaceae* have very suggestive life cycles which may throw light on the origin of some of the obscure life cycles of other *Algae* and the *Fungi*. In general there are four types of *Oedogonium*. 1 Species with normal hermaphrodites. 2 Species with normal unisexual plants, the male filaments being a little smaller in size than the female. 3 Hermaphroditic species in which the normal plant produces oogonia and androsporangia with androspores, the androspores producing dwarf male filaments with spermatozooids. 4 Species in which the filaments are unisexual, but the imperfect male filament, because of incomplete sexualization, produces only androspores, which germinate to produce the dwarf males with spermatozooids. The dwarf males appear to be an intercalated generation thru the parthenogenetic development of androspores which represent original spermatozooids.

The dwarf males range in the several species from unicellular to multicellular filaments. The androspores have not lost their primary male state entirely for they are usually attracted to the oogonium and settle down on it or in the cell immediately below. The reduction division probably takes place at the germination of the zygote. The life cycle of the third type of species is therefore as follows. Hermaphroditic haploid gametophyte with incomplete male sexualization, oogonium and androsporangium, androspores and immature eggs, dwarf male, antheridium on dwarf male, mature eggs and spermatozooids, fertilization in the oogonium, resting diploid zygote, reduction division in the zygote, four haploid zoospores, germination of zoospores. Had the egg also developed a parthenogenetic female filament, the result would have been a complete but peculiar type of alternation of generations, the parthenogenetic egg and sperm simulating a megaspore and a microspore. The life cycle is evidently a direct modification of the simple sexual cycle. See Fig 1 1a-1b-1c.

In *Coleochaete* the normal, simple, haploid, sexual cycle is present except that a vegetative phase is introduced between the reduction division and the nonsexual spores, so that 16-32 cells are produced instead of the usual 4, all of which develop into zoospores. The life cycle therefore is Haploid herma-

phroditic gametophyte, gametangia, gametes, fertilization in the oogonium, zygote, resting stage, germination of the zygote with reduction, haploid "sporophyte," nonsexual zoospores, germination of zoospores. This life cycle seems to be directly derived from the simple, haploid, sexual cycle. Another interpretation is possible by assuming that the two or more divisions following meiosis are a vestige of repeated divisions before zoospore production, handed down from a unicellular condition, but more probably they represent a mutative addition to the original cell lineage like the extra division stage which results in a 16-celled female gametophyte in some *Peperomias*.

PHAEOPHYTA The knowledge of the life histories and cytology of the Brown and Red Algae is still very incomplete, so it is impossible to delimit the larger groups with any certainty. A number of recent discoveries, however, make necessary a rearrangement of the classes of the Phaeophyta. All arrangements must be regarded at present as tentative.

In the Ectocarpales and probably all of the Phaeosporales proper, an alternation of generations seems to be lacking. Of the two types of sporangia produced, the unilocular sporangia are nonsexual and develop the nonsexual zoospores. The plurilocular sporangia are the sexual organs or gametangia. In some species at least, as in *Ectocarpus siliculosus* both unilocular sporangia and plurilocular gametangia may be present on the same individual at the same time. The gametes range from isogamous free-swimming gametes to heterogamous motile micro- and mega-gametes. In some species the female isogametes settle down first and the male gametes move to them, when conjugation takes place. Is the frond of *Ectocarpus* and related forms haploid or diploid? and where does reduction take place? Until these questions are answered for a considerable number of genera, no final classification of the Brown Algae is possible. The life cycle so far as known is: Gametophyte, unilocular sporangium with nonsexual zoospores repeating the gametophyte, plurilocular gametangium, gametes, fertilization, zygote.

The life cycle of *Fucus* is well known and is as follows: Diploid gametophyte, gametangia (unilocular), oocyte and spermatocyte, reduction divisions (meiosis), vegetative multiplication of incipient sexual cells, heterogametes, fertilization in the water, zygote, germination. This is not to be regarded

as a reduced alternation of generations as has sometimes been done, but as a simple diploid sexual cycle, with intercalation of cell divisions between meiosis and gamete maturation (development of primary sexual state) See Fig 1 2a-2b-2c

The greatest discoveries have been made by Sauvageau and others in the Laminariales or giant kelps, where a peculiar alternation of generations has been established for several genera But the real knowledge required for making proper deductions are again lacking The large frond is apparently a diploid organism and in Chorda, according to Kylin, the first division of the primary nucleus of the sporangium is a reduction division The sporangia are of the unilocular type and agree in this respect with the unilocular gametangia of the Cyclosporæ The spores produced in the unilocular sporangia of Lammaria and Postelsia develop into small male and female gametophytes The life cycle would then be Large, diploid frond (sporophyte), unilocular sporangium, reduction division, nonsexual zoospores, germination, small haploid female and male gametophytes, gametangia, gametes, zygote, germination

There appears to be a much closer relationship between the Laminariales and the Cyclosporæ, than between the former and the Phaeosporæ If we regard the Fucales and Laminariales as having a common primitive origin with a simple diploid sexual life cycle, then the Fucales have evolved by simply intercalating vegetative divisions between reduction and gametogenesis while the Laminariales have developed a small intercalated or secondary gametophyte thru the development of parthenogenesis in the originally isogamous gametes produced on the diploid plant The change took place in both male and female gametes and not in the male gamete alone as in Oedogonium The decided change in life cycle will warrant placing the giant kelps in a distinct class as has recently been done by some, otherwise they should be associated with the Cyclosporæ

DICTYOTAE The life cycle of these Brown Algæ indicates only a remote relationship to the other groups Dictyotas were probably segregated directly from the primitive phaeophyte stock and developed their alternation of generations cycle immediately after passing the unicellular condition The life cycle of Dictyota dichotoma is Haploid male and female gametophytes, gametangia, gametes, fertilization in

the water, zygote, germination, diploid nonsexual plant or sporophyte, sporangium, sporocyte, reduction, haploid tetraspores, germination. The gametophyte and sporophyte are both prominent plants.

RHODOPHYTA There are various life cycles in the red algae but apparently all have been derived from one common type. Not enough is known as yet to make conclusive deductions. The life cycle of *Polysiphonia* is a typical alternation of generations cycle with some complications and is well known. Haploid gametophyte, gametangia, gametes, fertilization by non-ciliated sperms in the oogonium, zygote, germination of diploid zygote in the oogonium, diploid carpospores, germination of carpospores, diploid sporophyte, tetrasporangium, sporocyte, reduction division, reduction spores (tetraspores), germination. Compare with Fig 1 3a-3b-3c-3d.

The life cycles of *Bangia*, *Batrachospermum*, and other genera seem to be somewhat different and *Bangia* and its relatives probably constitute a distinct class.

CHAROPHYTA The stoneworts, according to the investigations of Tuttle on *Nitella*, have apparently a simple, diploid sexual cycle, the plant being diploid with the $2X$ number of chromosomes and the reduction taking place in the gametangia. Diploid gametophyte, gametangia, reduction, gametes, fertilization in the oogonium, resting zygote, germination. The stoneworts are, therefore, quite distinct in life cycle from most of the other green algae.

FUNGI

Unfortunately, in the case of the fungi, as in various other groups of *Thallophyta*, the taxonomist meets with difficulty in attempting to compare the life histories of one group with another for the purpose of discovering phyletic relationships. There is much work for the cytologist. If, for example, the life history of various species of *Mucor* (*Rhizopus*) were definitely known and especially their nuclear activities during conjugation and reduction, one might be able to deduce some very important conclusions in relation to numerous experimental facts known about them as well as to their probable origin.

It is probable that in *Rhizopus* the reduction division takes place in the sporangium developed on the germ-tube. If this is the case and if we assume a relationship to the green

algæ with a simple haploid cycle, as for example the more primitive Siphonæ, then the germ-tube represents either an intercalated diploid or a conjugate generation, resulting from the cenocytic development of the zygospore. Whether the conjugation of the male and female nuclei takes place in the zygospore or in the sporangium of the germ-tube is not known. It seems reasonable, however, to consider the nuclei of the two conjugating branches as having originally been incipient isogamous gametes.

In *Saprolegnia monoica* the haploid mycelium is cenocytic. The oogonial and antheridial branches are decidedly dimorphic. Several female nuclei are left functional in the female gametangium and several male nuclei in the male gametangium. The male nuclei are discharged thru a penetrating tube into the oogonium. A single male nucleus unites with each egg, thus forming uninucleate zygotes. Reduction takes place at the germination of the zygote giving rise to the vegetative haploid mycelium. This is, therefore, a simple haploid sexual cycle.

In *Albugo* a single male or female nucleus functions in each gametangium. The resting zygote in some species produces zoospores on germination which is probably accompanied by a reduction division.

There has been much dispute about the origin and relationships of the ascomycetous and basidiomycetous fungi. Their life histories indicate that they originated from organisms with a simple haploid sexual cycle. In the meantime, a binucleated phase has been intercalated thru the partial desexualization of the sex nuclei before nuclear fusion has taken place, the complete primary sexual state with fusion being attained again at a later stage. The conjugate nuclei have not lost their primary sexual state entirely, however, since they must exert an influence on each other, otherwise it does not seem possible that conjugate division, thru which the binucleate mycelium is developed, could be accomplished.

A number of life cycles of the Ascomycetæ are fairly well known. *Pyronema confluens* according to the work of Harper and of Claussen, has a uninucleated haploid mycelium. The essential part of the life history is as follows. The male and female sexual branches become multinucleate, fuse, and the nuclei from the antheridium pass over into the oogonium. The nuclei partially lose their primary sexual state at this

time, if it is really fully developed, and simply pair off without fusing

Several hyphæ are produced from the oogonium and the pairs of conjugate nuclei pass into them and undergo several conjugate divisions. Thus each ascogenous hypha has binucleated cells, the pair of nuclei representing descendants of the original male and female nuclei produced. Following a complex process of division, a penultimate cell with a male and female nucleus, each with a complete primary sexual state, is finally produced and conjugation takes place, the delayed zygote. From this cell an ascus is developed in which reduction takes place giving rise to four free haploid nuclei, which with a further division give rise to the eight ascospores.

The binucleate stage arises thru the incomplete sexualization of the sex nuclei, preventing conjugation, vegetative divisions are intercalated and the binucleated condition is the result. The simulated "sporophyte" is a secondary development from an original simple, haploid sexual cycle. The binucleate phase in this case and in the basidiomycetous fungi can be called a conjugate generation. There is no evidence that the Ascomycetæ had an alternation of generations with a true sporophyte originally. In a normal sporophyte generation the nuclei are diploid, in a conjugate generation the cells contain conjugate, haploid nuclei. The generation ends by the sexualization of the conjugate nuclei and their fusion into a zygote nucleus rather than in the sexualization of synaptic chromosomes in a reduction division. Sexualization of the chromosomes with synapsis occurs at the germination of the zygote as in plants with a typical simple haploid sexual cycle. This conjugate phase seems to be developed only in the higher fungi and represents a new type of intercalated vegetative development between the fertilization and reduction stages. The fact that it is much less developed in the Ascomycetæ than in the more highly evolved Teliosporæ and Basidiomycetæ indicates that it has not degenerated from a true diploid sporophytic phase. It seems to become more prominent in the progressive evolution of the higher fungi.

The highest fungi show many of the peculiarities of the Ascomycetæ and even of the Phycomycetæ in relation to their sexual processes, indicating a close relationship as to origin. The same general method of fusion of the gametangia, the loss for a time of the primary sexual states of the conjugate nuclei,

and development to a greater or less degree of a binucleate cell condition strongly indicate a common origin, probably from uninucleate, haploid sexual green algae with isogamous gametes which, either in the algal stage, or after passing into the fungus condition, segregated into a cenocytic subphylum and a subphylum with uninucleated cells

In the rusts, *Caeoma nitens* may be a representative of the more primitive condition. On the other hand it is possible that it represents an abbreviated life history. At present the evidence does not seem to be sufficient to establish either proposition. *Caeoma* has a uninucleated, haploid mycelium. In the aecium stage the tips of branches representing male and female gametangia conjugate and the contents of the one pass over into the other. The nuclei lose their primary sexual state and become conjugate nuclei. A chain of binucleate aeciospores is produced. These spores on germination become zygotes when the conjugate nuclei develop complete primary sexual states and fuse into one. In some cases at least a reduction division follows with a promycelium or basidium and four haploid basidiospores. If this is the primitive condition, it shows but a slight development of the binucleate phase. But if characteristic teliospores do develop in some unknown stage of the life cycle it would have to be regarded as a derived condition, the conjugate generation being lost thru a change in the time of the complete sexualization of the conjugate nuclei. The pycnidia may represent vestigial conidial sori.

The life cycle is then: Haploid uninucleate sexual plant, uninucleate gametangia, conjugation of cells and cytoplasmic union, partial loss of primary sexual state of the conjugate nuclei, a number of vegetative conjugate divisions resulting in the formation of aeciospores, complete sexualization of the conjugate nuclei, nuclear fusion resulting in a diploid nucleus or zygote, development of a basidium or promycelium with reduction division, four haploid basidiospores.

In some of the rusts, as in *Puccinia graminis*, the binucleated phase or conjugate generation has been extensively developed. The life cycle is: Haploid uninucleate mycelium on the barberry, uninucleate gametangia, conjugation and cytoplasmic union; pairing of the sexual nuclei without fusion, a number of conjugate divisions to produce aeciospores, germination of binucleate aeciospores on wheat, binucleate mycelium, vegetative propagation by binucleate uredospores, production

of teliospores, complete sexualization of the conjugate nuclei in the teliospore, fusion of sexual nuclei to form the diploid uninucleate condition or zygote proper, germination of zygote (teliospore) with reduction division, promycelium or basidium with four haploid uninucleate basidiospores, germination of basidiospore on the barberry again. This cycle can readily be derived from the simple, haploid sexual cycle.

The basidiomycetæ appear to present the same fundamental conditions as the other fungi, namely, a modification of the simple, haploid sexual cycle at the isogamous stage of sexual evolution. The vegetative body appears to begin as a haploid mycelium with uninucleate cells. Later cells may become cenocytic by fragmentation of the nuclei or cenocytic divisions. At the beginning of the development of the fruiting body and earlier, a conjugation of gametangia normally takes place, resulting in binucleate cells and a conjugate mycelium. A peculiar method of division of the binucleate cells gives rise to the "clamp connections" and is carried on in such a way that each cell receives a pair of the conjugate nuclei. Finally basidia are formed at the tips of hyphal branches in the fruiting body, the conjugate nuclei become sexualized in the incipient basidia, unite, and form the diploid zygotic nucleus. Reduction follows, typically with four reduction nuclei which develop the four uninucleate, haploid basidiospores.

A careful study of some of the known life cycle of the Ascomycetæ, Teliosporæ and true Basidiomycetæ shows that these groups are much more closely related than was formerly supposed. The relationship between the rusts and typical basidiomycetous fungi has been recognized for some time, but many still hold to a special origin of the Ascomycetæ. But the character of the vegetative body together with the remarkable similarity of the fundamental stages in the life cycle and the very similar sexual modifications far outweigh the slight resemblance and the duplication of superficial characters which the ascocarp may have to the sporocarps of the red algæ. The writer is convinced of the primary monophyletic origin of all the Mycomycetæ.

LIFE CYCLES OF THE META-THALLOPHYTA

The Meta-thallophytes present no such difficulties or complexities in their life cycles as the Thallophytes. All the life cycles belong to a single type with clear modifications, the

typical antithetic alternation of generations cycle The cycle simply becomes more complex with the upward progress of evolution, the fundamental stages and conditions remaining unchanged In Fig 2 are represented the twelve fundamental, antithetic stages, which show that there is no exactly similar life cycle in any of the Thallophytes

The life cycles of the main groups of higher plants are given below without special discussion, since they are well known and involve no diversity of views as to their nature

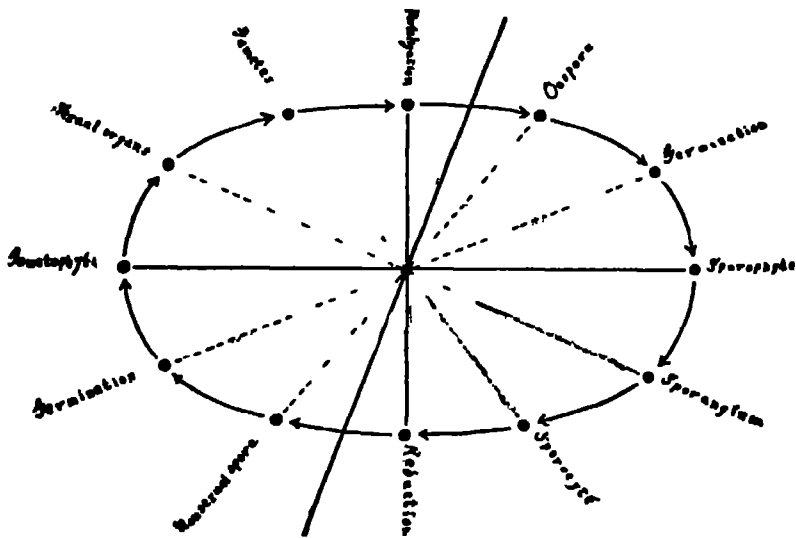


Fig 2 Diagram showing the principal stages in the life cycle of the higher plants From the author's Laboratory Outlines for General Botany Fifth edition

Whatever one may think about the origin of the antithetic cycle it is now completely established on a single type as stated above

MARCHANTIA Haploid male and female gametophytes, archegonium (ovary) and antheridium (spermary), female and male gametes (oosphere and spermatozoid), fertilization, zygote (oospore), germination in venter, diploid parasitic sporophyte, sporangium, sporocyte, reduction division (with primary sexual states in the synaptic chromosomes), non-sexual spores (reduction spores or tetraspores), germination on the ground See Fig 2 and Fig 1 3a-3b-3c-3d

TYPICAL MOSS Haploid hermaphroditic gametophyte with protonema and gametophore phases, archegonium and antheridium, oosphere and spermatozoid, fertilization, oospore, germination in venter, diploid parasitic sporophyte, sporangium; sporocyte, reduction, nonsexual spores, germination on the ground

TYPICAL FERN Haploid hermaphroditic gametophyte; archegonium and antheridium, oosphere and spermatozoid, fertilization, oospore, germination in venter, diploid sporophyte with parasitic embryonic and independent mature phases and with indeterminate growth, sporophyll, sporangium, sporocyte, reduction, nonsexual spores, germination on the ground

EQUISETUM ARVENSE Haploid male and female gametophytes which show much sex reversal, archegonium and antheridium, oosphere and spermatozoid, fertilization, oospore, germination in venter, diploid sporophyte with parasitic embryonic and independent mature phases and with indeterminate and determinate shoots, reproductive determinate shoot or flower (strobilus), sporophyll, sporangium, sporocyte; reduction, nonsexual spores, germination on the ground

MARSILEA QUADRIFOLIA Reduced haploid male and female gametophytes (connected with the spore wall), archegonium and antheridium, oosphere and spermatozoid, fertilization, oospore, germination in venter, diploid heterosporous bisporangiate sporophyte with dependent and independent phases and with indeterminate axes, sporophyll with enclosed sporocarps, sex-determination in the sorus, megasporangium and microsporangium, megasporocyte and microsporocyte, reduction divisions, megaspore and microspore, germination in the water

SELAGINELLA Reduced haploid male and female gametophytes connected with the spore walls; archegonium and antheridium, oosphere and spermatozoid, fertilization, oospore; germination in venter, diploid heterosporous bisporangiate sporophyte with dependent embryonic and independent mature phases and with determinate and indeterminate axes, bisporangiate strobilus with sex-determination in the incipient sporophylls, megasporophyll and microsporophyll, megasporangium and microsporangium; megasporocyte and microsporocyte, reduction divisions, megaspore and microspore; beginning of germination in the sporangia, completion of development of gametophytes on the ground

CYCAS. Parasitic haploid male and female gametophytes, development of pollen-chamber in the young ovule, discharge of male gametophytes (pollen grains) and pollination in pollen-chamber, development of parasitic pollen-tube and second period of development of male gametophyte, archegonium (ovary) and reduced antheridium, oosphere and spermatozoid, discharge of spermatozooids into archegonial chamber, fertilization; oospore with determination of sex, germination in venter inside of the megasporangium (ovule), embryonic diploid parasitic carpellate and staminate sporophytes, resting condition of embryonic sporophytes in the ovule (mature seed), discharge of seed, sprouting of seed in ground; juvenile independent sporophytes developing into the mature carpellate and staminate sporophytes—the former with indeterminate reproductive axis, the latter with a determinate reproductive axis, the staminate strobilus, megasporophyll (carpel) and microsporophyll (stamen), megasporangium (ovule) and microsporangium (pollen sack), megasporocyte and microsporocyte, reduction with sexualization of the synaptic chromosomes, megaspore and microspores, germination of the two kinds of spores in the sporangia

PINUS Parasitic haploid male and female gametophytes in the microsporangium and megasporangium, discharge of the male gametophyte (pollen) with pollination on the micropyle of the ovule, development of pollen-tube and second parasitic phase of the male gametophyte, archegonium (ovary) and reduced antheridium, oosphere and nonmotile sperms, primary sexualization of the gametes, discharge of the sperms into the archegonium venter, fertilization, germination of oospore, development of diploid parasitic sporophytic embryos (polyembryony), survival of one embryo with resting condition of the surviving embryo sporophyte in the seed, discharge of the seed; sprouting of embryo in seed, juvenile independent sporophyte, mature neutral sporophyte, determination of male and female sexual states in certain buds (monecious condition); staminate and carpellate strobili or cones (flowers), megasporophyll (carpel) and microsporophyll (stamen), megasporangium (ovule) and microsporangium (pollen sack), megasporocyte and microsporocyte, reduction divisions with primary sexualization of the synaptic chromosomes, megaspore and microspore, germination of the two kinds of spores in the sporangia to produce the gametophytes again

ALISMA SUBCORDATUM Greatly reduced parasitic haploid female and male gametophytes in the megasporangium and microsporangium (ovule and pollen sack), discharge of the male gametophytes (pollen), pollination on stigma, the carpel being closed and forming an ovulary, development of pollen-tube with second parasitic phase of the male gametophyte, egg apparatus (greatly reduced ovary or archegonium) and greatly reduced antheridium (two spermatogenous cells), oosphere and two polar nuclei and two nonmotile sperms, development of primary sexual states in the five cells, discharge of the sperms into the female gametophyte, fertilization and triple fusion, diploid oosphere and triploid definitive or primary endosperm nucleus, germination of oospore and division of definitive nucleus, parasitic diploid embryonic sporophyte and parasitic triploid xeniophyte (endosperm) in the seed, resting stage of sporophyte embryo, discharge of fruit containing seed, sprouting of embryo sporophyte, juvenile stage of independent sporophyte, mature neutral diploid sporophyte, development of flower, determination of sex, originally the male state with later reversal to female state (bisporangiate flower), megasporophyll (carpel) and microsporophyll (stamen), megasporangium (ovule) in the ovulary and microsporangium (pollen sack), megasporocyte and microsporocyte, reduction divisions with primary sexualization of the synaptic chromosomes, megaspores and microspores, germination of the two spores in the sporangia to produce the parasitic gametophytes again. See Fig 1, 3a and 4a, 3b and 4b, 3c, 3d

Note The differentiation of normal megaspores has been eliminated by abbreviation of the cell lineage. In many Angiosperms four megaspores are developed following reduction, one of which is functional.

CANNABIS SATIVA The life cycle is essentially the same as in *Alisma* except that sexualization in the sporophyte takes place in the oospore, giving rise to the diecious condition with carpellate and staminate, highly dimorphic sporophytes. Under certain conditions sex reversal takes place abundantly in the growing sporophyte.

By comparing the life cycles from the Bryophytes to the Angiosperms it will be noted, as stated before, that they are all of one fundamental type with a gradual development of complexity in the evolution toward the highest condition.

THE GENUS MOUGEOTIA

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The species belonging to this genus are among the most widely distributed of all the freshwater algæ. In the vegetative condition they have been collected in arctic, temperate, and tropical regions of all of the continents and on the most isolated of the Pacific islands. They likewise occur in lakes, ponds, and temporary pools, and in all manner of springs, streams and rivers. In lakes they often form a part of the plankton either as isolated cells, or as short straight or coiled filaments. In permanent streams and ponds *Mougeotia* may be found throughout the year, while in temporary bodies of water they are among the first algæ to appear after a rainy period.

Certain species of *Mougeotia* exhibit a union of pairs of cells in adjoining filaments and a subsequent bending of the cells at the points of contact. This is known as "genuflexing" and was described by some of the earliest students of the filamentous algæ (Vaucher 1803, p. 79, Pl. 8). Some of these earlier students mistook genuflexing for conjugation, and Hassall limited the Genus *Mougeotia* to species that "reproduce" in this way.

Genuflexing is most frequently observed in *M. genuflexa* and its variety *gracilis*, but I have also observed it in *M. laetevirens*, *M. pulchella*, and *M. notabilis*. The phenomenon has been interpreted (1) as incipient conjugation, (2) as preparation for vegetative multiplication through the disintegration of the filaments and subsequent cell division, and (3) as a reaction for "interchange of soluble substances."

Genuflexing occurred every year in a certain pond in central Illinois from which I have frequent collections over a period of years. There it usually began early in April and continued until July or August. The mass of *Mougeotia* increased until late June or July and then decreased until there were only the usual scattered filaments the remainder of the summer. In the Autumn, vegetative *Mougeotia* became abundant, but there was no genuflexing. It is futile to assign physiological and ecological "functions" to this process since in the united knee-

joint cells, the chloroplasts usually contract and after a time the cells disintegrate and fall to the bottom. The continuation of vegetative growth comes mostly from those filaments that do not unite. Those who must have a function for genuflexing had best look upon it as a suicidal union due to unknown causes. Conjugation may occur when genuflexing is going on or at a different time. In another pond I have also observed genuflexing in which cells of two different species were united—one about half the size of the other. The species probably were *M. genuflexa* and *M. notabilis*, since both these species had been collected there previously in a fruiting condition.

In many shaded ponds in this latitude and in ponds of alpine and arctic regions vegetative growth apparently continues from year to year without change in form of the cells. Scattered akinetes (thick-walled vegetative cells) are formed. The four records from my Illinois collections falling in May, June, July and August.

Aplanospores are the only known reproductive structures in five of the species *M. ventricosa*, *M. tropica*, *M. mayori*, *M. prona*, and *M. tenerrima*. Aplanospores are the usual mode of reproduction in *M. boodlei*. *M. calcarea* and *M. notabilis* are occasionally found producing only aplanospores, and aplanospores are usually present when these species are found fruiting sexually. Of the remaining thirty-seven species, aplanospores have been found in fourteen. We may say, therefore, that asexual reproduction by aplanospores is now known in twenty-two of the forty-five species described in this paper. G. S. West suggested that "there is in the early stages of aplanospore formation a more or less complete division of the protoplast into two parts which subsequently fuse together." This suggestion probably is based on the widely copied statement of Paul Petit that in *Spirogyra mirabilis* the aplanospores (which he regarded as zygosporos) are formed in this way. I have examined hundreds of these aplanospores in all stages of development in several species of *Spirogyra*, *Mougeotia* and *Zygnema* and have never seen a cell in which the nucleus and cytoplasm divided and subsequently fused. Wittrock was quite right in his observation that in *M. ventricosa* the chromatophore may divide in the middle and the two halves pass into the swollen part of the sporogenous cell so that finally the nucleus lies between them. I have seen the same process in *M. boodlei*, *M. notabilis*, and *M. prona* (see Pl. VII, Fig. 111), but in none

of these did the cytoplasm or nucleus divide. In most instances the cytoplasm and the included structures merely aggregate toward the middle of the cell with loss of water and the subsequent formation of sporangium and spore walls. The initial cells of the aplanospores are usually about twice the length of the average vegetative cells, but there are numerous examples in which they are no longer than the vegetative cells.

In conjugation adjoining cells in different filaments develop protuberances which fuse and form a conjugating tube. In *M. genuflexa* and *M. scalaris* (in lateral conjugation) these protuberances may develop from adjoining cells of the same filament. Usually the protuberances are in contact from the beginning, but in many cases they are not in contact until later. I believe the same statement holds in scalariform conjugation but in that case it is impossible to prove except by direct observation.

As the conjugating tubes are being formed the chromatophores and most of the cytoplasm move into the tube, the median portions first. The tube then swells rapidly and may become several times the thickness of the filaments. The gametangia are then cut off by one, or two walls, depending upon whether or not the gametes pass completely into the conjugating tube. In the first instance the sporangium is "adjoined by two cells," i. e., the gametangia remain undivided, in the second case the sporangium is "adjoined by four cells," i. e., the middle part of each gametangium is occupied by a part of the sporangium. Subsequently a spore wall is secreted and this is usually yellow, brown, or blue, but in several species it is colorless. The spore wall may be smooth, punctate, scrobiculate, pitted or wrinkled.

Twin zygospores and combinations of zygospores and parthenospores are common in *M. capucina*. In these cases one or both gametes divide before the fusion of the gametangia (see Pl. X, Figs. 67 and 68).

The genus *Mougeotia* as here defined includes the species formerly described in the genera *Gonatonema*, *Craterospermum*, *Mesocarpus*, *Plagiospermum*, *Staurospermum*, and *Pleurospermum*.

The writer has examined all the specimens of *Mougeotia* distributed in Wittrock and Nordstedt's *Algæ aquæ dulcis exsiccataë*, Collin's, Holden, and Setchell's *Phycotheca Boreali-Americana*; Tilden's *American Algæ*, those in the U. S. National Herbarium, and other specimens sent him by the late Professor

Nordstedt, Professor Borge, (Stockholm), the late Professor Farlow, Dr Cedercreutz, (Helsingfors), Dr M Higashi, (Tokio), Dr D B Anderson, Dr L H Tiffany, Dr G E. Nichols, Dr W M Barrows and Dr F C Baker His own collections include specimens from most of the states east of the Mississippi River

MOUGEOTIA (Agardh, 1824) Wittrock, 1872

Key to the Species

- | | |
|--|---------------------------------|
| 1 With aplanospores (zygospores rare or unknown) | 33 |
| 1 With zygospores (rarely aplanospores also) | 2 |
| 2 Sporangium between 2 undivided gametangia (adjoined by 2 cells) | 3 |
| 2 Sporangium dividing one of the gametangia (adjoined by 3 cells) | 21 |
| 2 Sporangium dividing both gametangia (adjoined by 4 cells) | 22 |
| 3 Sporangium globose, subglobose, ovoid or ellipsoid | 4 |
| 3 Sporangium cylindric with concave sides | 18 |
| 3 Sporangium compressed spherical, compressed ovoid, or compressed ellipsoid | 19 |
| 4 Spore wall smooth | 5 |
| 4 Spore wall punctate, diam veg cells 11-14 μ | 16 <i>M ovalis</i> |
| 4 Spore wall scrobiculate, pitted or wrinkled | 16 |
| 5 Diam veg cells usually less than 12 μ | 6 |
| 5 Diam veg cells usually more than 12 μ , less than 24 μ | 9 |
| 5 Diam veg cells usually more than 24 μ , less than 40 μ | 13 |
| 5 Diam veg cells more than 40 μ | 15 |
| 6 Spores globose | 7 |
| 6 Spores more or less ellipsoid, longer axis, 20-28 μ | 2b <i>M parvula ellipsoides</i> |
| 6 Spores variable, some extending into the gametangia | 1 <i>M calcarea</i> |
| 7 Outer sporangium wall a thick transparent pectic layer | 20 <i>M victoriensis</i> |
| 7 Sporangium without outer pectic layer | 8 |
| 8 Diameter spores 7-8 μ | 2a <i>M parvula angusta</i> |
| 8 Diameter spores 13-24 μ | 2 <i>M parvula</i> |
| 9 Spores variable, some extending into gametangia | 1 <i>M calcarea</i> |
| 9 Spores globose | 10 |
| 9 Spores ovoid to quadrate ovoid | 12 |
| 10 Sporangium wall with pectic layer, spores blue | 19 <i>M maltae</i> |
| 10 Sporangium wall without pectic layer, spores brown | 11 |
| 11 Diameter spores 23-33 μ | 3 <i>M recurva</i> |
| 11 Diameter spores 30-40 μ | 5 <i>M scalaris</i> |
| 12 Diameter spores 24-30 μ , cong lateral | 14a <i>M genuflexa gracilis</i> |
| 12 Diameter spores 40-45 μ cong scalariform | 10 <i>M sphaerocarpa</i> |
| 13 Spores more than 50 μ in diameter | 13 <i>M macrospora</i> |
| 13 Spores 30-40 μ in diameter | 14 |
| 14 Cong scalariform, spores usually globose | 5 <i>M scalaris</i> |
| 14 Cong usually lateral, spores quadrately globose | 14. <i>M genuflexa</i> |
| 15 Spores about 40 μ in diameter | 11 <i>M subcrassa</i> |
| 15 Spores 60 μ or more in diameter | 12 <i>M crassa</i> |
| 16 Diameter vegetative cells 8-16 μ , sp diam less than 40 μ | 4 <i>M nummuloides</i> |
| 16 Diameter veg cells 17-20 μ , sp diam more than 40 μ | 6 <i>M megaspora</i> |
| 16 Diameter veg cells 22 μ or more | 17 |
| 17 Spores globose, wall wrinkled, diameter 30 μ | 7 <i>M gottlandica</i> |
| 17 Spores ovoid wall punctate 30 μ x 40 μ | 8 <i>M pulchella</i> |
| 17 Spore ovoid, wall scrobiculate, 38 μ x 50 μ | 9 <i>M robusta</i> |

- | | | |
|--|------------------------------------|----|
| 18 Spores 20μ in diameter | 21 <i>M. angolensis</i> | |
| 18 Spores $30-50\mu$ in diameter | 22 <i>M. laevivirens</i> | 20 |
| 19 Spores with thick outer transparent pectic layer | | |
| 19 Spores without a thick outer layer, diameter veg cells $7-12\mu$ | 16 <i>M. depressa</i> | |
| 20 Spores brown, diameter veg cells $13-18\mu$ | 17 <i>M. gelatinosa</i> | |
| 20 Spores blue, wall punctate, diameter veg cells $14-20\mu$ | 18 <i>M. cyanea</i> | |
| 21 Spores variable, globose to ovoid or quadrate, diameter $30-40\mu$ | 1 <i>M. calcarea</i> | |
| 21 Spores globose not filling the 3-lobed sporang, diameter $16-20\mu$ | 23 <i>M. notabilis</i> | |
| 21 Spores cylindric, $48-56\mu \times 0.4-0.78\mu$ | 22a <i>M. laevivirens</i> variants | |
| 22 Spore wall smooth | | 23 |
| 22 Spore wall punctate, scrobiculate, or verrucose | | 28 |
| 23 Diameter veg cells more than 12μ | | 24 |
| 23 Diameter veg cells less than 10μ | | 25 |
| 24 Spores brownish violet with angles produced | 37 <i>M. capucina</i> | |
| 24 Spores quadrate regular, with sides $22-28\mu$ long | 26 <i>M. fragilis</i> | 26 |
| 25 Angles of zygosporangia rounded or undulate truncate | | |
| 25 Angles of zygosporangia retuse margins concave | 25 <i>M. viridis</i> | 27 |
| 25 Angles of zygosporangia produced | | |
| 26 Diameter veg cells $3.5-4.5\mu$ | 24 <i>M. elegantula</i> | |
| 26 Diameter veg cells $8-9\mu$ | 27 <i>M. virescens</i> | |
| 26 Diameter veg cells $11.5-13.5\mu$ | 28 <i>M. palmidosa</i> | |
| 27 Diameter veg cells $4-5\mu$, zyg irreg, processes truncate | 31 <i>M. americana</i> | |
| 27 Diameter veg cells $5-6\mu$, zyg rounded, processes short rounded | 34 <i>M. corniculata</i> | |
| 27 Diameter veg cells $6-8\mu$, zyg wall very thick, processes long rounded | 35 <i>M. uberosperma</i> | 29 |
| 28 Spore wall punctate | 33 <i>M. gracillima</i> | |
| 28 Spore with concave sides, wall verrucose | | |
| 28 Spore with convex sides, wall minutely scrobiculate | 39 <i>M. tumidula</i> | 30 |
| 29 Diameter veg cells 13μ or less | | 32 |
| 29 Diameter veg cells more than 13μ | | 31 |
| 30 Zygosporangia quadrate | | |
| 30 Zygosporangia cruciate quadrate, diameter veg cells $8-10\mu$ | 40 <i>M. punctata</i> | |
| 30 Zygosporangia quadrate with angles produced | 42 <i>M. producta</i> | |
| 31 Diameter veg cells $4-5\mu$, reproduction mostly by aplanospores | 29 <i>M. boodleyi</i> | |
| 31 Diameter veg cells $8-13\mu$, sides of zygosporangia $28-40\mu$ | 32 <i>M. quadrangulata</i> | |
| 32 Zygosporangia ovoid-globose $38-46\mu \times 38-48\mu$ | 43 <i>M. aspera</i> | |
| 32 Zygosporangia irregular quadrate, with long processes | 38 <i>M. irregularis</i> | 35 |
| 33 Diameter veg cells $4-5\mu$, spores oblique ellipsoid | 36 <i>M. tropica</i> | 34 |
| 33 Diameter veg cells $6-7\mu$, spores oblique globose | | |
| 33 Diameter veg cells $8-13\mu$ | 45 <i>M. mayori</i> | |
| 33 Diameter veg cells $13-16\mu$, spores oblique ellipsoid, punctate | 1 <i>M. calcarea</i> | |
| 34 Aplanospores globose to ovoid smooth, diam. $17-21\mu$ | 41 <i>M. prona</i> | |
| 34 Aplanospores ellipsoid with retuse ends, punctate | | |
| 34 Aplanospores ovoid to ellipsoid, $12-24\mu \times 16-20\mu$, smooth | 44 <i>M. ventricosa</i> | |
| 35 Spore wall smooth | 30 <i>M. tenerima</i> | |
| 35 Spore wall punctate | 29 <i>M. boodleyi</i> | |

1 *M. calcarea* (Cleve) Wittrock, 1872

Bih. till K. Sv. Vet. Akad. Handl. I, No. 1, *Sphaerospermum calcareum* Cleve, 1868, *Mougeotia sphaerica* Gay, Essai d'une Monographie locale des Conjuguees Montpellier, 1884, *Gonatonema sphaerospora* Borge, Arkiv for Botanik, 1282 1903

Vegetative cells $8-14\mu \times 40-280\mu$, chromatophore 5-7 the cell length, cells elongating and becoming geniculate before spore formation, zygospores globose, $25-30\mu$ in diameter or angular-globose, $22-28\mu \times 30-50\mu$, wholly in the tube, or extending into one or both gametangia, spore wall smooth, colorless, aplanospores globose, lateral to the sporogenous cell or extending into the sporogenous cell, $17-21\mu$ in diameter, or rarely trapezoid ovoid dividing the sporogenous cell, $15-20\mu \times 20-28\mu$

United States Illinois, Michigan, Mississippi, Ohio Sweden, France, Greenland, North Africa, Brazil, British Columbia

(Plate I, Figs 9-14)

This is the most variable of all the described species and shows all of the types of spore formation which led the early students of the group to postulate several distinct genera. In Mississippi, Illinois and Brazil only the aplanospores have been found

a-var *bicalyptirata* (Wittrock) comb. nov.

W & N Alg. Exsic. No. 741 Bot. Not. 1886, p. 135

Vegetative cells $10-12\mu \times 30-110\mu$, zygospores with thickened end walls adjoining the gametangia, sometimes completely closing the gametangia

United States Michigan British Columbia, Sweden

(Plate I, Fig. 8)

2 *M. parvula* Hassall, 1843

Ann. and Mag. Nat. Hist. 11 434

Vegetative cells $6-12\mu \times 30-140\mu$ chromatophore usually occupying two-thirds of the cell with 4-6 pyrenoids, sporangia adjoined by two cells, zygospores formed wholly in the conjugating tube, globose, $13-24\mu$ in diameter, wall thick, smooth, brown, aplanospores obliquely ovoid, $16-20\mu \times 20-24\mu$

United States Massachusetts, Rhode Island, Michigan, Ohio, North Carolina British Isles, Germany, Austria, Switzerland, France, Sweden, Norway, Belgium, Finland, Czecho-Slovakia, Brazil, Japan.

(Plate I, Figs 1-3)

a-var *angusta* (Hass.) Kirchner 1878

Alg. Schles., p. 128. *Mesocarpus angustus* Hass. 1845, *Sphaerocarpus angustus* Hass., 1843a.

Vegetative cells $5-6\mu \times 30-95\mu$, zygospore diameter $7-8\mu$.

United States South Carolina British Isles, Germany, Austria, Belgium, Czecho-Slovakia

b-var *ellipsoides* W & G S West, 1907

Ann Roy Bot Gard, Calcutta, 6, part 2

Vegetative cells as in the type, zygospores ellipsoid.

Burma.

(Plate I, Figs. 4-5)

3 *M recurva* (Hass.) De Toni, 1889

Sylloge Algarum, p 714 *Mesocarpus recurvus* Hassall, 1845, *Sphaerocarpus recurvus* Hassall, 1843a.

Vegetative cells $12-18\mu \times 50-180\mu$, sporangia adjoined by 2 cells, zygospores globose, $23-33\mu$, median spore wall smooth, brown, aplanospores globose (diam 24μ) at the angles of geniculate cells, or cylindric ovoid $14\mu \times 34\mu$ in straight cells

United States Douglas Lake, Michigan British Isles, Germany, Australia, South America

(Plate I, Figs 6-7)

4. *M nummuloides* (Hassall) De Toni, 1889

Sylloge Alg, p 713, P B A. 714

Vegetative cells $8-16\mu \times 32-160\mu$, sporangia adjoined by 2 cells, zygospores globose to ovoid $17-37\mu$ in diameter, aplanospores ovoid within the angled sporogenous cell, median spore wall brown, scrobiculate

United States Maine, Massachusetts, New Jersey, North Carolina, Ohio British Isles, Belgium, Luxemburg, Germany, Sweden, Czechoslovakia, Finland

(Plate I, Figs. 15-16)

5 *M scalaris* Hassall, 1842

Ann. and Mag Nat Hist, 10 34

Vegetative cells $20-34\mu \times 40-180\mu$, fertile cells straight or slightly curved, sporangia adjoined by 2 cells, zygospores ovoid to globose $30-38\mu$ (40μ) in diameter, median wall smooth, yellow-brown, occupying the conjugating tube

United States South Carolina, Georgia, Illinois, New Jersey, Pennsylvania, Florida, Iowa, Ohio Great Britain, Sweden, Belgium, France, Russia, Italy, Germany, Czechoslovakia, Queensland, New Caledonia, Japan, Luxemburg

(Plate II, Figs. 25-27)

a-var *macrospora* Hirn 1895

Acta Soc pro Fauna et Flora Fennica 11, No 10.

Vegetative cells $25-28\mu \times 60-140\mu$, zygospores ovoid larger than the type, $40-48\mu \times 43-50\mu$.

United States Michigan Finland

6 *M. megaspora* Wittrock, 1872

Bih till K Sv Vet Acad Handl 1 No 1

Vegetative cells $17-19.5\mu \times 170-380\mu$, sporangia adjoined by 2 cells, zygosporangia globose to ovoid, $41-44\mu \times 45.5-48\mu$, median spore wall brown, irregularly scrobiculate

Sweden

(Plate II, Fig 23)

7 *M. gotlandica* (Cleve) Wittrock, 1872

Bih till K Sv Vet Akad Handl 1 No 1

Vegetative cells about $22\mu \times 75-150\mu$, sporangium adjoined by 2 cells, zygosporangia globose, about 30μ in diameter, median spore wall yellow brown, wrinkled

Sweden Luxemburg

(Plate II, Fig 24)

8 *M. pulchella* Wittrock, 1871

Hedwigia p 88

Vegetative cells $24.29\mu \times 48-150\mu$, sporangium adjoined by 2 cells, zygosporangia ovoid to ellipsoid with ends more or less flattened, $28-35\mu \times 40-50\mu$, median spore wall yellow-brown, punctate

United States Douglas Lake, Michigan Sweden, Germany

(Plate IV, Fig 53)

9 *M. robusta* (De Bary) Wittrock, 1885

W & N Alg Exsicc No 651

Vegetative cells $25-33\mu \times 75-260\mu$, chromatophores with many irregularly distributed pyrenoids, zygosporangia adjoined by 2 cells, ovoid to subglobose, $35-41\mu \times 47-54\mu$, wall scrobiculate, brown

United States Iowa, Ohio, Massachusetts, New Jersey, Illinois Germany, Japan

(Plate III, Figs 39-41)

A rather common species in the eastern United States Both the species and variety have occasional filaments with two parallel chromatophores in each cell, or a single chromatophore more or less divided toward the ends Distinguished from *M. gotlandica* (Cleve) Wittrock by its larger dimensions, and the color and marking of the spore wall, from *M. pulchella* Wittrock by the reddish brown color of the spores

a-var *biornata* Wittrock, 1884

W & N Alg Exsicc, No 615 Bot No t 1884, p 126

Vegetative cells $22-30\mu \times 25-240\mu$, zygosporangia $30-38\mu \times 42-50\mu$, outer wall inwardly verrucose, fitting the scrobiculations of the median wall

United States Illinois, Iowa, Ohio, Michigan Sweden, Ceylon.

The structure of the outer wall may be readily demonstrated by crushing a spore and adding a drop of potassium hydroxide or some other reagent that will cause the wall to swell

10 *M sphaerocarpa* Wolle, 1887

Freshwater algæ, p 227 *M minnesotensis* Wolle, 1887, *M divaricata* Wolle, 1887

Vegetative cells $19-24\mu \times 60-120\mu$ ($\sim 240\mu$), gametangia curved, usually 4-6 pyrenoids, zygospore in the greatly enlarged conjugating tube, or extending into the gametangia, ovoid to subglobose, $40-45\mu$ in diameter or ovoid $36-40\mu \times 40-55\mu$, wall smooth, brown, aplanospores ovoid to obliquely ovoid $24-30\mu \times 35-50\mu$

United States Minnesota, New Jersey, Pennsylvania, Illinois, Iowa, Ohio, California, Florida
(Plate III, Figs 28-33)

var *varians* var nov

Vegetative cells $24-28\mu \times 100-240\mu$, aplanospores ovoid $34-36\mu \times 38-42\mu$, zygospores frequently ovoid $35-44\mu \times 44-60\mu$, touching one or both of the outer walls of the gametangia

Manila, Philippine Islands (Collected by Walter R Shaw)
(Plate III, Figs 34-35)

This new variety superficially resembles *Debarya africana* G S West, but differs in the thickening of the end walls of the gametangia and in the fact that only a part of the contents of the conjugating cells enter the zygospore

11 *M subcrassa* G S West, 1906

Jour Linn. Soc Bot, 39.50

Vegetative cells $41.5-43\mu \times 240-280\mu$, chromatophore with 15-24 pyrenoids deposited irregularly, conjugating cells straight or slightly curved, zygospores globose between two undivided gametangia, $40-41\mu$ in diameter, outer wall smooth and indistinctly lamellate Sporangial wall thicker at the ends of the tube.

Victoria, Australia
(Plate IV, Fig 54)

12 *M crassa* (Wolle) De Toni, 1889

Sylogæ algarum, p 716, *Masocarpus crassus* Wolle, Bull Torrey Bot Club, 12 127, 1885

Vegetative cells about $50\mu \times 200-500\mu$ spores globose, about 65μ in diameter, filling the tube, not extending into the gametangia, outer wall smooth.

United States Florida
(Plate III, Fig 38)

The large size of the vegetative cells distinguishes this from all other described species I have found vegetative filaments of these dimensions in Illinois, Mississippi and Alabama, but the fruiting record is based on Wolle's collection and description

13 *M. macrospora* (Wolle) De Toni, 1889Sylloge Algarum, p 716, *Mesocarpus macrosporus* Wolle, 1887

Vegetative cells about $30\mu \times 180-300\mu$, gametangia slightly recurved, sporangia adjoined by 2 cells, zygospores globose, $55-60\mu$ in diameter, outer wall smooth, fully occupying the greatly enlarged tube

United States Pennsylvania, New Hampshire

(Plate III, Fig 36)

Distinguished from *M. sphaerocarpa* Wolle and *M. crassa* (Wolle) De Toni, which it resembles, by the differences in dimensions of both vegetative cells and spores. The species seems not to have been found since Wolle's records and his specimens are lost

14 *M. genuflexa* (Dillwyn) Agardh, 1824Systema Alg p 83 *Mesocarpus pleurocarpus* DeBary, *Mougeotia mirabilis* (A Br) Witt

Vegetative cells $25-38\mu \times 50-225\mu$, often geniculate and attached to other similar cells forming extensive nets, sometimes with rhizoidal branches, conjugation lateral, less frequently scalariform, sporangia adjoined by 2 cells, zygospores quadrately ovoid to globose, $30-40\mu$ in diameter, wall smooth, brown

United States Maine, Massachusetts, Connecticut, New Jersey, Pennsylvania, Michigan, Minnesota, Illinois, Iowa, Ohio, Louisiana, British Isles, Sweden, Denmark, Belgium, Luxemburg, Germany, Russia, Austria, France, Czecho-Slovakia

(Plate IV, Figs 43-44)

a-var *gracilis* Reinsch, 1867

Die Alg Flora von Franken, p 215 P B A 312

Vegetative cells $15-24\mu$ in diameter, zygospores $24-30\mu$ in diameter, otherwise like the type

United States Illinois Germany, Czecho-Slovakia, Java

(Plate IV, Fig 45)

15 *M. depressa* (Hassall) Wittrock, 1880Skandinavien vaxter, part 4 *Mesocarpus depressus* Hass 1845, *Sphaerocarpus depressus* Hass, 1843a.

Vegetative cells $7-12\mu \times 35-144\mu$, sporangia adjoined by 2 cells, conjugation lateral and scalariform, zygospores compressed ellipsoid $12-14\mu \times 28-32\mu$, longer axis parallel to the filaments, median wall punctate, brown

United States Gainesville, Florida. British Isles, Germany, Sweden, Luxemburg

(Plate II, Fig 20)

Evidently closely related to *M. parvula* Hass, from which it differs in the form of the spore and spore wall

16 *M. ovalis* (Hassall) Nordstedt, 1886

W & N Alg. Exsicc., No 742 Botaniska Notiser, 1886, p 136

Vegetative cells $11-14\mu \times 110-140\mu$, sporangia adjoined by two cells, zygospore compressed ovoid to subglobose $26-36\mu \times 29-38\mu$, median spore wall pitted

British Isles, Italy, Germany

(Plate III, Fig 37)

17 *M. gelatinosa* Wittrock, 1889

W & N Alg. Exsicc. No 957, fasc 21, pp 26-27

Vegetative cells $13-18\mu \times 120-180\mu$, sporangium adjoined by 2 cells, zygospores compressed ovoid, $38-47\mu \times 28-39\mu$, not including the outer pectic layer, which may be $7-10\mu$ in thickness, median spore wall brown, smooth

British Isles, Sweden, Finland

(Plate II, Fig 17)

In this and the three following species the pectic layer is quite transparent and is visible largely through the accumulation of clay particles on its exterior surface. At maturity the pectic layer may be absent from some of the spores, apparently having gone into solution

18 *M. cyanea* sp. nov.

Vegetative cells ($14-$) $16-18\mu$ ($\sim 20\mu$) $\times 160-200\mu$, chromatophore occupying one-third to one-half of the cell, with 4 to 10 pyrenoids in a straight line, zygospores compressed spherical $30-40\mu \times 38-48\mu$ with the longer axis parallel to the filaments, aplanospores spheroidal, laterally placed in the sporogenous cell, $30-32\mu$ in diameter, both kinds of spores surrounded at maturity with a transparent pectic layer 4μ to 8μ thick, spore wall finely punctate, blue

United States Douglas Lake, Michigan (Collected by G. E. Nichols)

(Plate II, Figs 21-22)

19 *M. maltae* Skuja, 1926

Acta Horti Botanici, Univ. Latviensis, 1: 109 Fig 1 and Pl. I, Fig 1

Vegetative cells $17-22\mu \times 60-120$ (~ 200) μ , chromatophore nearly as long as the cell with 4 to 8 pyrenoids, conjugating cells slightly incurved, zygospores globose (30) $-32-35$ (40) μ in diameter, spore wall smooth, blue, surrounded by a gelatinous layer 4 to 6μ in diameter

Usma Lake, Latvia

(Plate II, Fig 18)

20 *M. victoriensis* G. S. West, 1909

Jour. Linn. Soc. Bot., 39: 51

Vegetative cells $11-12\mu \times 100-160\mu$, chromatophores with two to seven, usually 5 or 6, pyrenoids arranged in a single slightly irregular

series, conjugating cells recurved, zygospores globose contained within the tube, median spore wall smooth, surrounding the sporangium a layer of pectic material develops which extends even beyond the outer sides of the gametangia. Diameter of the spores $21-24\mu$, diameter including the pectic coat, $60-63\mu$.

Victoria, Australia

(Plate II, Fig 19)

21 *M. angolensis* W & G S West, 1897

African Freshwater Algae, Jour Bot 35.39

Vegetative cells $25-29\mu \times 100-145\mu$, chromatophores with 4 to 6 very small pyrenoids irregularly disposed, zygospores short cylindric with concave sides, $19-21\mu$ in diameter, wall smooth, gametangia slightly curved

Angola, Africa

(Plate IV, Fig 42)

The chromatophore has fewer pyrenoids and the zygotes are smaller than in *M. lacteovirens* (A Br) Witttr

22 *M. lacteovirens* (Braun) Wittrock, 1877

W & N Alg Exsicc, No 58, Bot Notiser, 1877, p 23.

Vegetative cells $22-40\mu \times 65-350\mu$, many pyrenoids irregularly disposed conjugating cells geniculate, sporangia adjoined by 2 cells, zygospores contained in the tube, outer wall short cylindric, $36-47\mu \times 45-72\mu$ with concave sides, aplanospores ovoid or obliquely ovoid, median wall smooth, yellow-brown

United States Ohio, New Jersey, Long Island, N Y, Michigan, New Hampshire, Massachusetts, Wisconsin, North Carolina Sweden, Germany, Luxemburg, Czecho-Slovakia, Finland, Queensland, Paraguay, Outer Mongolia, Brazil.

(Plate IV, Figs 46-50)

a.-var *varians* Wittrock, 1886

W & N Alg Exsicc, No 740, Bot Notiser, 1886, p 135

Zygospores extending into or across the gametangia, sporangia adjoined by 2, 3, or 4 cells, spores $48-56\mu \times 64-78\mu$.

Sweden, Germany, Czecho-Slovakia

(Plate IV, Figs 51-52)

23 *M. notabilis* Hassall, 1840

Ann and Mag Nat Hist, 10 46 *Plagiospermum tenuis* Cleve, 1888, *Mongosia tenuis* (Cleve) Wittrock, 1872, *Mongosia Transsion* Collins, 1912

Vegetative cells $10-18\mu \times 50-250\mu$, usually only one gametangium is divided by the sporangium which is consequently triangular ovoid; zygospores not completely filling the sporangia, more or less ovoid to subglobose, $24-28\mu \times 26-36\mu$, aplanospores obliquely ovoid to trapezoid $16-20\mu \times 23-30\mu$, sporogenous cell geniculate or straight, spore wall smooth

United States Illinois, Iowa, Ohio, Pennsylvania, New Jersey, Florida Sweden, British Isles

(Plate V, Figs. 55-59)

There is no doubt about the identity of the species figured by Hassall It contained only aplanospores and is quite similar to immature aplanosporic material found in Illinois Collins' species was described from the first material of the kind which I found in Illinois Subsequently an abundance of material was found which established the identity of the three species I have seen material upon which Wille based his *Mougeotia tenuis* var *crassa*, and it is typical of *M. notabilis*

24 *M. elegantula* Wittrock, 1872

Om Gotlands, etc , p 40

Vegetative cells $3.5-4.5\mu \times 50-135\mu$, chromatophores with 4-8 pyrenoids, conjugating cells geniculate, sporangium adjoined by 4 cells, zygosporangia cruciate-quadrate, $18-24\mu$ with smooth, hyaline walls, the corners rounded

United States Massachusetts, Illinois, Michigan Sweden, West Indies

(Plate VI, Figs 84-87)

25 *M. viridis* (Kuetz) Wittrock, 1872

Om Gotlands, etc , p 39

Vegetative cells $6-8\mu \times 24-80\mu$, chromatophores occupying most of the cell with 4-6 pyrenoids, zygosporangia adjoined by 4 cells, quadrate with concave sides, and retuse angles, $22-32\mu$ on the side, aplanospores oblique ellipsoid, $14-16\mu \times 30-36\mu$, median spore wall smooth, colorless.

United States New Jersey, Wisconsin, Illinois, Florida British Isles, Sweden, Germany, Czecho-Slovakia, Austria, Hungary, France, Belgium, Russia, Finland, Luxemburg

(Plate VII, Figs. 97-98)

26 *M. fragilis* (Zeller) De Toni, 1873

Hedwigia, p 174

Vegetative cells $17-22\mu \times 85-200\mu$, zygosporangia quadrangular with sides $22-28\mu$ long Spore wall smooth

Pegu, Burma.

27 *M. virescens* (Hassall) Borge, 1923

Zygnematales in Pascher's Susswasserflora, 9 43, *Staurocarpus virescens* Hassall, 1845

Vegetative cells $8-9\mu \times 30-110\mu$, sporangia adjoined by 4 cells, zygosporangia quadrate, with concave sides, $29-34.5\mu$, wall colorless, smooth, with rounded corners

British Isles

(Plate VII, Fig 104)

27 *M. paludosa* G S West, 1899

Algal flora of Cambridgeshire Jour Bot 37 108, pl 395, figs 4-6

Vegetative cells $11.5-13.5\mu \times 70-185\mu$, chromatophores short, occupying about one-third the length of the cell with about 5 pyrenoids, fertile cells recurved, zygospores ovoid to quadrangular ovoid, adjoined by 4 cells, angles undulate truncate, outer wall of zygospore thick, colorless, spores $32-38\mu \times 44-49\mu$

Cambridgeshire, England
(Plate V, Figs 73-75)

Distinguished from all other species by the thick colorless spore wall with its undulate truncate angles Probably nearest *M. capucina* (Bory) Agardh from which it is readily distinguished by its smaller dimensions and absence of the violet color

29 *M. Boodleyi* (W & G S West) Collins, 1912

Tufts College Studies, 3 60

Vegetative cells $4-5\mu \times 25-225\mu$, chromatophore 5-8 the length of the cell, with 4-6 pyrenoids, zygospores quadrate, $15-18\mu \times 15-23\mu$, corners somewhat rounded, aplanospores ellipsoid, $12-15\mu \times 23-25\mu$, projecting slightly on the convex side of the slightly curved sporangia, spore wall punctate, yellow-brown

United States Illinois British Isles
(Plate VI, Figs 78-80)

30 *M. tenerrima* G S West, 1914

Mem Soc neuchatelouse Sci Nat 5 1028

Vegetative cells $4.5\mu \times 110-135\mu$, chromatophores with 6 pyrenoids in one series, zygospores unknown, aplanospores oblique-ellipsoid, $12-13\mu \times 24-25\mu$, ends slightly mamillate, wall smooth

South America Columbia.
(Plate VI, Figs 81-83)

31 *M. americana* Transeau, 1918

Tech Pub No 9, N Y State Coll of Forestry, p 237

Vegetative cells $4-5\mu \times 40-120\mu$, conjugating cells slightly or strongly geniculate, zygospore adjoined by four walls, irregularly quadrate with concave or convex sides, angles produced and truncate, the space between the zygospore and the sporangium walls being filled with pectic material, $13-24\mu \times 18-32\mu$, wall smooth, transparent, aplanospores obliquely elliptical, ends truncate at the middle of very long geniflexed vegetative cells, $10-14\mu \times 20-26\mu$

Oneida Lake, N Y, Douglas Lake, Mich.
(Plate VI, Figs 88-93)

32 *M. quadrangulata* Hassall 1843

Ann and Mag of Nat Hist 11 434. DeBary, 1858, Splanospermum quadratum

Vegetative cells $8-13\mu \times 50-140\mu$, with 8 to 16 pyrenoids in a line, conjugating cells geniculate, sporangia adjoined by 4 cells, zygospores

quadrate with straight sides and truncate corners or rarely with angles retuse, $28-40\mu$ on a side, with colorless, punctate wall, aplanospores obliquely ovoid, $20-21\mu \times 36-44\mu$

United States Illinois, Ohio, Michigan, Massachusetts, New Jersey, North Carolina, Florida British Isles, Belgium, Germany, Russia, France, Czecho-Slovakia Sweden, Austria, Poland

(Plate V, Figs 70-72)

33 *M gracillima* (Hassall) Wittrock, 1872

Om Gotlands, etc p 40

Vegetative cells $5-7\mu \times 55-140\mu$, sporangia adjoined by 4 cells (rarely 3), zygospor quadrately, with deeply concave sides, $20-25\mu \times 20-28\mu$, angles retuse, wall minutely verrucose

United States Illinois, New York, Massachusetts, Michigan British Isles, Sweden, Luxemburg, Germany, Czecho-Slovakia, France

(Plate VI, Figs 95-96)

34 *M corniculata* Hansgirg, 1886

Oesterr Botan Zeitschr, No 10

Vegetative cells $5-6\mu \times 30-180\mu$, sporangia adjoined by 4 cells, zygospor quadrately ovoid, $22-26\mu \times 22-26\mu$, median spore wall yellow-brown, smooth, thickened, forming rounded processes at the corners

Czecho-Slovakia

(Plate VI, Fig 94)

35 *M uberosperma* W & G S West, 1897

Welwitsch's African Freshwater Algæ Jour Bot 35 37

Vegetative cells $6-8\mu \times 24-64\mu$, fertile cells recurved, zygo sporangia dividing both gametangia, zygospor angular globose (4-6 angles), wall very thick and lamellate, colorless, with corners extended into 4 solid unequal processes which project into the gametangia, diameter of the zygospor $21-27\mu$, processes $3-18\mu$ long Aplanospore $20\mu \times 30\mu$ with two processes

Angola and Kentani, Africa

(Plate VII, Figs 102-103)

36 *M tropica* (W & G S West, 1916

Algæ, p 337, Annals of Botany 12 39, Pl 4, *Gonatonema tropicum*, Jour Bot 35.38, 1897

Vegetative cells $6-7\mu \times 36-56\mu$ with two pyrenoids in the chromatophore, zygospor unknown, aplanospores obliquely globose with projecting mamillate solid processes, median wall yellow-brown, scrobiculate, $27-28\mu \times 27-29\mu$, with the processes $42-46\mu$ in length

Angola, Africa

(Plate VII, Fig 112)

37 *M. capucina* (Bory) Agardh, 1824

Systema algarum, p 84, *Siaurospermum capucinum* De Bary, 1858, p 81

Vegetative filaments usually violet colored, cells $14-21\mu \times 70-280\mu$ (-340μ), chromatophore with 4-6 (-8) pyrenoids, frequently rod-shaped, occupying one-third to one-fourth the length of the cell, or ribbon-like containing 12-16 chromatophores in a line and extending three-fourths the length of the cell, sporangium walls formed at a distance ($5-52\mu$) from the zygospore, the intervening space being filled with pecto-cellulose compounds, sporangium dividing both gametangia, zygospores irregularly quadrangular with concave sides $50-70\mu \times 60-100\mu$, wall violet-brown, thick especially at the angles, smooth, aplanospores not uncommon $20-36\mu \times 45-70\mu$ (-80μ) with more or less thickened ends.

United States Long Island, N Y, North Carolina, Florida, Alabama, British Isles, France, Sweden, Belgium, Switzerland, Italy, Brazil, New Zealand

(Plate V, Figs 62-69)

38 *M. irregularis* W & G S West, 1897

Welwitsch's African Freshwater Algae Jour Bot 35 38.

Vegetative cells $13.5-15\mu \times 70-90\mu$, conjugating cells more or less recurved, sporangium dividing both gametangia, zygospores irregularly quadrate or trapezoid with concave sides and thick walls, angles with horn-like processes of varying length with rounded ends, median spore wall thick, yellow to yellow brown, punctate, extreme length of zygospore including the processes $38-63\mu$, extreme width, $42-48\mu$

Angola, Africa

(Plate V, Figs 60-61)

39 *M. tumidula* Transeau, 1914

Amer Jour Bot 1.297

Vegetative cells $6-8.5\mu \times 70-120\mu$, chromatophore with 4 to 8 pyrenoids, sporangia adjoined by 4 cells, zygospores quadrate, somewhat tumid $22-26\mu \times 26-30\mu$, angles retuse, walls colorless, minutely but distinctly scrobiculate, aplanospores obliquely ellipsoid $12-14\mu \times 28-32\mu$, with retuse ends and scrobiculate wall

United States Illinois, Iowa.

(Plate VII, Fig 105)

40 *M. punctata* Wittrock, 1867

Algologiska studier, I Upsala.

Vegetative cells $8-10\mu \times 50-120\mu$, sporangia adjoined by four cells; zygospores quadrate, $30-38\mu$ on a side, $18-20\mu$ thick, sides concave with obtuse angles, outer wall crenulate, inner nearly smooth

Upland, Sweden.

(Plate VII, Figs 99-101)

41 *M. prona* sp nov

Vegetative cells $8-12\mu \times 60-140\mu$ (-280μ) with 6 to 12 pyrenoids; aplanospores $20-24\mu \times 40-52\mu$ (-60μ), sporangium obliquely ellipsoid

with ends produced and truncate, spore wall faintly yellow and finely punctate with retuse ends

United States Long Island, N Y

(Plate VII, Figs 109-111)

This species occurred abundantly in 1924 in a rivulet below a roadside spring on the south side of High Hill. It produced aplanospores throughout July and early August. Distinguished from *M. tumidula* Transeau by its larger size and yellowish walls, from *M. quadrangulata* (Hass) Witttr by the retuse angles and yellowish walls. Evidently near *M. punctata* Witttr, but no zygosporos, which might have connected it with that species were found

42 *M. producta* G S West, 1907

Freshwater Algae from Burma. Annals Royal Bot Gard, Calcutta 6, part 2

Vegetative cells $7-8\mu \times 84-160\mu$, zygosporangia adjoined by 4 cells, zygosporos quadrate, with concave or slightly convex sides, angles produced and truncate, $29-37\mu$ on a side, aplanospores obliquely ellipsoid with ends produced and with a similar thickening near the ends, $14-18\mu \times 30-40\mu$, median spore wall punctate, colorless

Burma

(Plate VII, Figs 113-114)

43 *M. aspera* Voronikhin

Notulae syst ex Inst Crypt Horti bot Petropolitani, 2 102 Petrograd, 1923

Vegetative cells $13-16.5\mu \times 78-112\mu$, sporangium adjoined by 4 cells, zygosporos globose, $36-46\mu$ in diameter, rarely ovoid $46\mu \times 66\mu$, median spore wall pale brown, punctate

Tiflis, Georgia (Asia Minor)

44. *M. ventricosa* (Wittrock) Collins, 1912

Tufts College Studies, 3 69

Vegetative cells $5-9\mu \times 100-140\mu$, zygosporos unknown, aplanospores obliquely ellipsoid to subglobose, $12-24\mu \times 16-20\mu$, median spore wall smooth, yellow-brown

United States Pennsylvania, California, Michigan Europe.

(Plate VII, Figs 106-108)

45 *M. mayori* G S West, 1914

Mem Soc Neuchateloise d Sci Nat 5, 1927

Vegetative cells $13-15\mu \times 235-315\mu$ with 11 to 14 pyrenoids, aplanospores $24-26\mu \times 34-38\mu$, obliquely ellipsoid with truncate ends, median spore wall yellow, punctate

Central Andes of Columbia, South America

(Plate V, Figs 76-77)

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- Figs 4-5 *M. parvula* var *ellipsoideis*—After W & G West, 1907 Burma
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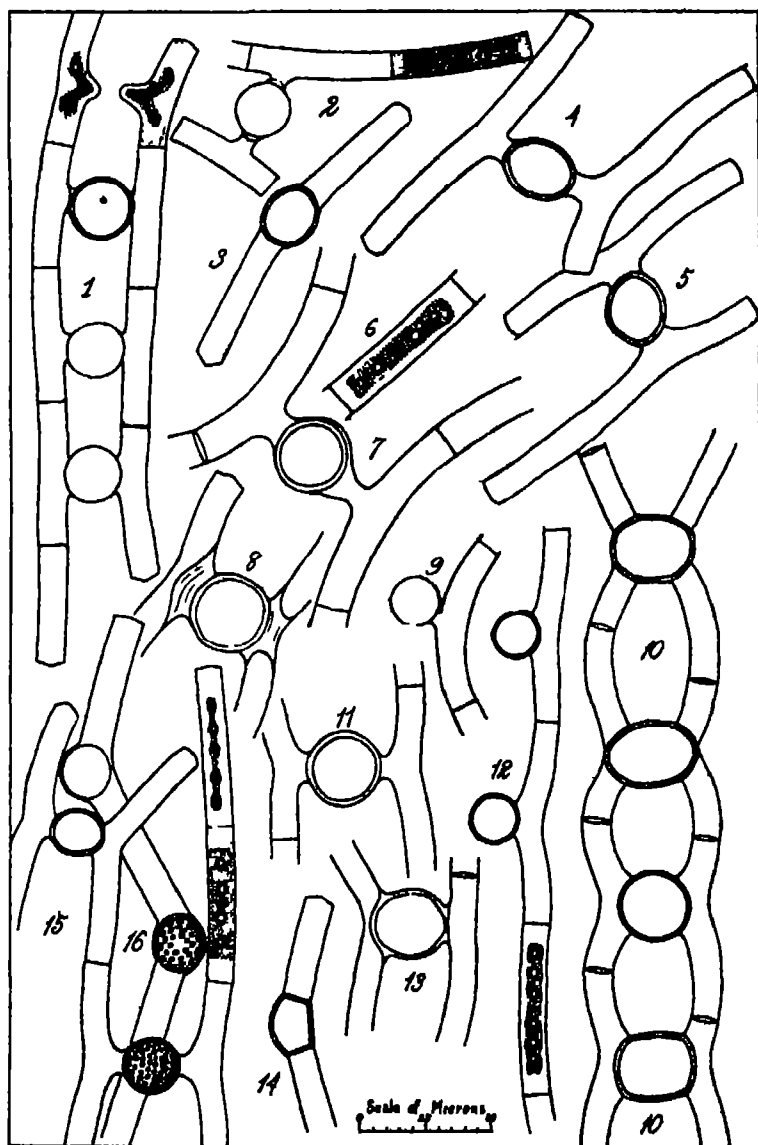
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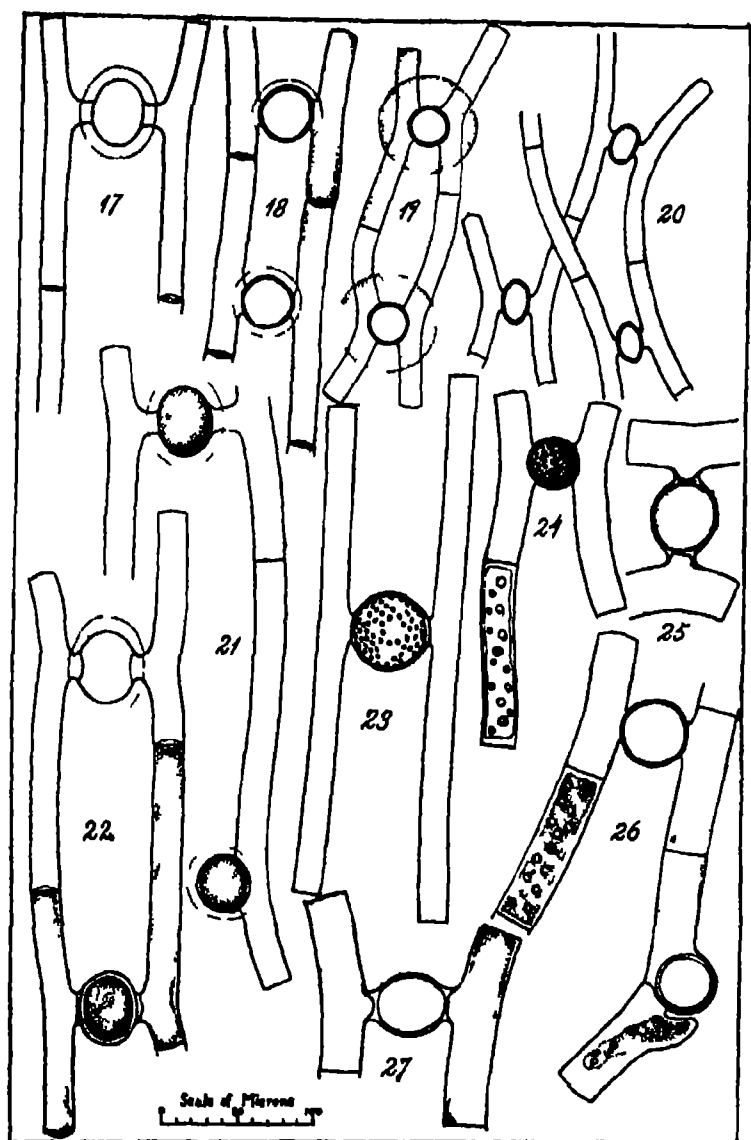
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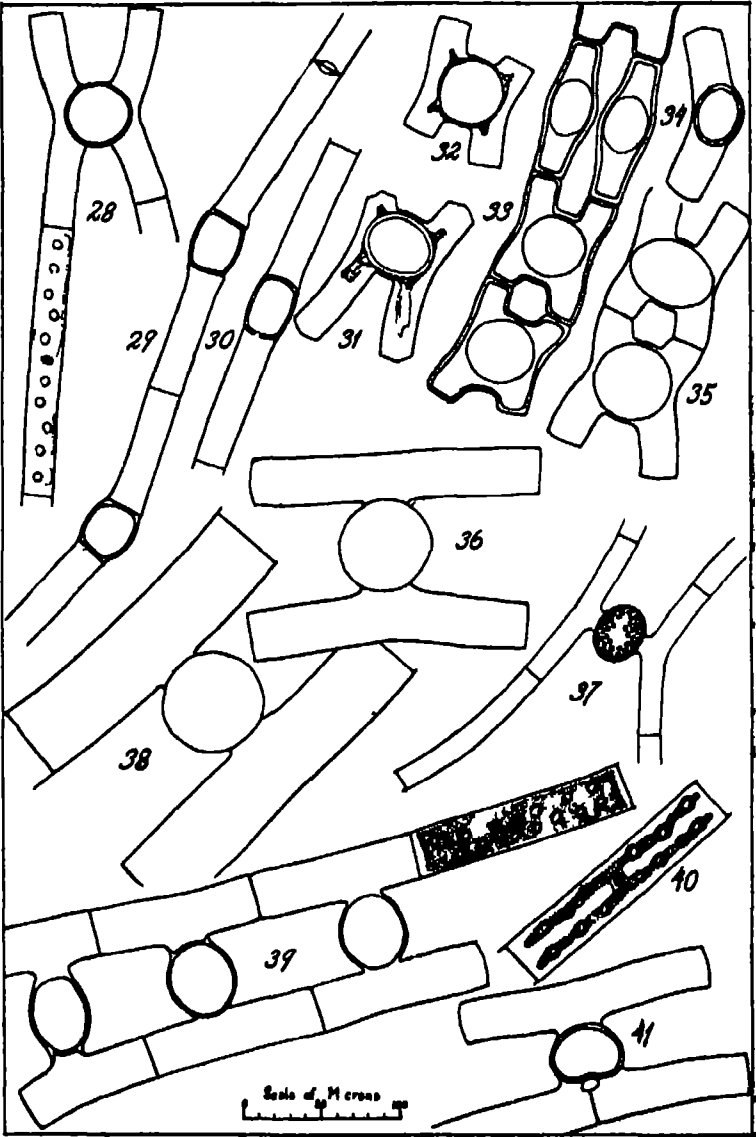
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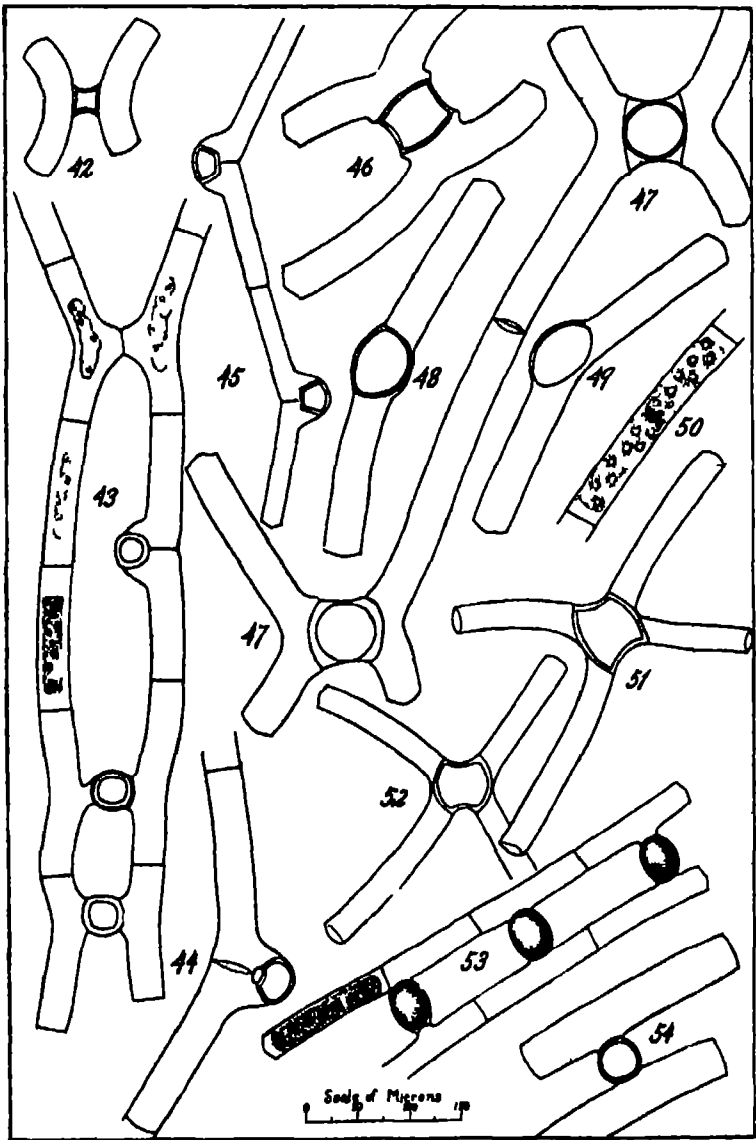
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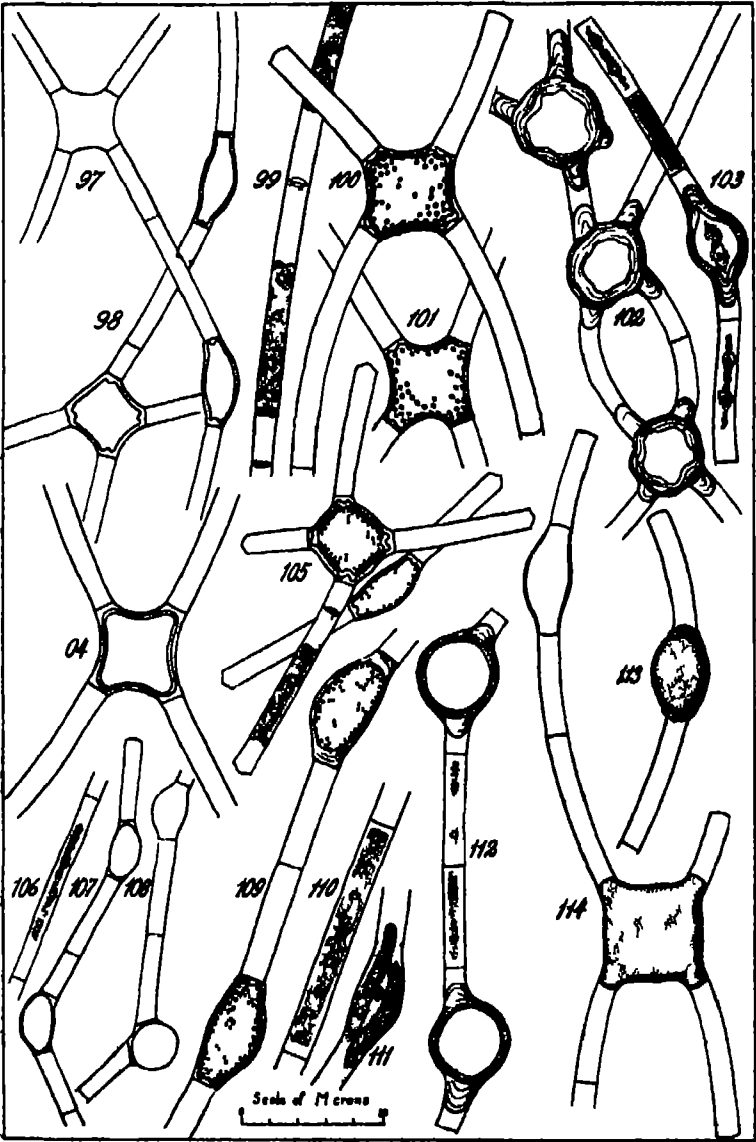
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